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House of the Society—127 East Twenty-third Street, New York.

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XXX.—October, 1893.)

THE TESTING OF PORTLAND CEMENT AND THE DEVELOPMENT OF THE CEMENT INDUSTRY IN GERMANY.

By MAX GARY, Civil Engineer, Berlin, Germany.

Translated from the German by JOHN S. SIEBERT, Instructor in Civil Engineering, Lehigh University.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

When, in 1852, the idea of utilizing the English invention of the manufacture of Portland cement first appeared in Germany, no one anticipated the growth this industry was destined to have, a growth which soon outstripped that of the mother-country, England.

As early as 1824, Joseph Aspdin, of Leeds, made a hydraulic lime by calcining a certain mixture of slaked lime and clay, which on account of its resemblance in color and hardness to the Portland stone, much valued at that time in England, he called Portland cement. The English product was soon introduced into Germany, and for a long time was considered unequaled. Not till 1852 was attention directed to the occurrence of the septaria clay in Pommerania, on the banks of the Oder, which was declared by Dr. Hermann Bleibtreu, of Bonn, to be

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

suitable material for the manufacture of cement. He also, in conjunction with Consul Gutike, erected at Züllchow, near Stettin, a small plant for experimental purposes, which led in 1855 to the founding of the first Stettin Portland cement factory (Lossius & Dellbrück), on what is now the property of the Züllchow works. Here, for the first time in Germany, Portland cement was made out of Stettin clay and chalk from the Island of Wollin, a cement which equaled the English product in quality and so quickly found favor that the annual production of 30 000 barrels was sold without special difficulties.

This success incited imitation, and in rapid succession the factories (most of them in existence to-day) of Bonn, "Lebbin, Oppeln," Lüneburg, Amöneburg, Finkenwalde and others sprang into existence. In 1877, there were in Germany 30 Portland cement factories, which at first copied closely the English methods of manufacture. At present the method of manufacture varies greatly in the different factories, according to the combination in which the requisite ingredients, carbonate of lime and clay, occur in the limestone, marble, chalk and other raw materials used.

Factories following the English methods generally employ the wet process.

The selection of the clays when a pure septaria cannot be employed, and the mixing in proper proportions of lime and clay (about 75% carbonate of lime to 25% of clay), constitute the real difficulties in cement-making to-day. After this the principal requirement for obtaining good Portland cement lies in a thorough mixing of the ingredients which are to be chemically combined by calcination. The two other divisions of manufacture, calcining at a very high temperature (burning to slag), and the grinding of kiln products, are well understood. Unquestionably, the wet process of to-day does not mix the ingredients so efficiently as the dry process, especially in those factories which work a fine limestone and mortar; but it is not to be denied that the rapid improvements in mill machinery may again cause a change in this. In some factories a combination of the two methods has already been adopted, the so-called half-dry process being used, in which the fine mortar and clay in proper proportions are mixed partly dry, in order to obtain the benefits of the best parts of each process. But mixtures of limestone and clay which may be at once burned to cement are rarely found in Nature.

It would exceed the limits of this paper to enter into a description of the chemical qualities of Portland cement and the development of the methods of manufacture, the making, drying, burning and grinding of the cement bricks; let us rather deal with the finished product and its mechanical properties, and state in what manner the quality of German Portland cement was systematically improved and how, in Germany more than elsewhere, efforts have been made, with the aid of scientific investigations, to probe the nature of Portland cement, bring its hidden properties to light and render them useful.

Before German Portland cement gained the world-wide fame it now enjoys, it had to overcome manifold difficulties. From the first, the competition with the English factories was severe. The low shipping rates and the extensive commerce of the home of Portland cement constantly drew large quantities of the English product to the German ports, and the reduction made in railroad tariffs for the benefit of these ports favored the introduction of a large part of this product into the interior. At the large ports on the North Sea the effect of English competition was especially marked, owing to the comparatively great distance of the German cement factories, and to this day the English product has not been entirely displaced. But in Central and South Germany the English competition, though favored by the natural waterway of the Rhine, has been compelled to abandon the field in favor of home factories erected in that region. Prejudice against German Portland cement and in favor of the foreign product was a further obstacle to its rapid introduction, to overcome which required long-continued efforts of the German manufacturers, perfected methods of manufacture and unceasing scientific labors of the large number of investigators who entered the service of this industry. To-day every German factory has in its employ one or more scientifically educated chemists whose duty it is to study the raw materials and the intermediate and finished products. Besides the powerfully equipped English factories, the competition of continental neighbors, especially Austria and Switzerland, had to be overcome; and, finally, the greatest of all obstacles, the prejudices against it arising from the long use of other low-priced and poorer mortar materials and ignorance of the new. The lack of knowledge regarding methods of test on the part of the consumer caused cheaper varieties of cement to be used and created a deep distrust of Portland cement, not only among builders, but even among the authorities.

Despite all these obstacles, the German Portland cement industry grew rapidly, as may be seen from the following table, based on the annual voluntary reports of the members of the Association of German Cement Manufacturers, who represent the major part of the German cement interests.

Year.	Number of factories.	Annual product in barrels @ 170 kg. (374 lbs.) net	Year.	Number of factories.	Annual product in barrels @ 170 kg. (374 lbs.) net.
1877	29	2 400 000	1887	45	7 050 000
1882	32	3 050 000	1888	52	7 950 000
1883	34	4 000 000	1889	60	8 800 000
1884	37	4 700 000	1890	60	9 150 000
1885	42	5 000 000	1891	60	9 950 000
1886	42	5 700 000	1892	62	10 600 000

More precise figures, giving a faithful picture of the development of the German cement industries during the last years, are available only since the introduction of the accident insurance law and the organization of industrial associations. According to the official reports of the quarry associations to which the German cement manufacturers belong, the development of this industry may be shown by the following statement:

Year.	Number of cement factories.	Number of men *permanently employed @ 300 working days.	Salaries paid. (Marks.)	Year.	Number of cement factories.	Number of men * permanently employed @ 300 working days.	Salaries paid. (Marks.)
1886	124	11 883	8 263 437	1889	149	16 388	12 294 665
1887	121	13 610	9 555 614	1890	159	19 174	14 839 656
1888	146	13 352	11 108 539	1891	158	19 503	15 166 627

* The number of "men permanently employed" was computed by dividing the total number of days all the men were employed in any one year by 300, this being taken as the customary number of working days in one year.

From the first table it is seen that the number of large Portland cement manufactories in Germany has been doubled in 15 years and the output increased fourfold in the same time.

From the second table it may be seen that the number of workmen employed and the sum paid in wages nearly doubled in five years. This table also includes a number of small factories, notably those of upper Bavaria, which employ but few hands and whose market is confined to

the country immediately adjoining. Such a tremendous growth of a comparatively young industry in so short a time was rendered possible only by the fact that the knowledge of the value of the Portland cement spread rapidly in the interior; that the demand from this region grew accordingly, and that the German product was successful in overcoming the opposition of foreign brands. The impartial recognition of the merits of German Portland cement by well-known foreign authorities, especially those of England, did much to further this end.

Mr. Henry Reid, author of "The Science and Art of the Manufacture of Portland Cement," in his book, "A Practical Treatise on Natural and Artificial Concrete,"* concludes his remarks about the difficulties met by cement manufacturers and builders in the manufacture and use of Portland cement, with the explanation that English manufacturers have every reason to improve their product. That this is not difficult, although necessary, he proves by the example set by the German Portland cement manufactory of "Stern," Toepffer, Grawitz & Co., at Stettin. He gives a description of their factory and what it had accomplished, showing that German Portland cement, even at that time, was able to compete with English cement, and promised eventually to become everywhere an opponent not to be left out of consideration.

What is here said of the one brand answers for all the German output of that time; the German manufacturers were most earnestly engaged in securing recognition of their product throughout the world. As a result, General Gillmore, as President of the Committee of Award at the Centennial Exposition in Philadelphia, designated the "Stern" cement as the best Portland cement sent there; and Professor Renleaux was enabled to announce at the session of the Central Association of Commercial Geography at Berlin, April 22d, 1880, that the reports of the Australian World's Exhibition held in Sydney declared: "The German cement was unquestionably the best." To-day this cement finds a market in all parts of the globe. The foreign countries grouped about the Baltic are regular customers, as also are Southern Russia, Switzerland, Belgium and Holland. But the sale in European countries probably falls short of that in the transoceanic ones. The United States of North America have thus far afforded the largest market. The countries of the Pacific Ocean come next, especially the more important harbors of Australia, as well as Japan and China.

* Published 1879, by E. & F. M. Spon, 46 Charing Cross, London.

Efforts for constant improvement went hand in hand with the growth of the German cement trade, not only because the field so laboriously won at home had to be maintained, but because it was necessary to widen the market for the increased production. To do this, it was absolutely necessary to understand the properties of cement, and how to utilize the same to full advantage. To reach these ends was the chief aim of the Association of German Cement Manufacturers, founded in 1877, which, with but few exceptions, all German manufacturers have joined, together with 18 Portland cement manufacturers of foreign countries. This association, at its general annual session, furnishes its members an opportunity to increase their knowledge of the properties of cement by verbal exchange of ideas, while the distribution of the printed stenographic reports of the session insures the publication of new facts and discoveries in the realm of cement, and enables the building public to keep pace with the advances in cement technique. Up to the time of the formation of this society uniform methods of judging the mechanical properties of cement were totally wanting, and testimony of the earnest work of the society may be found in the fact that, in 1877, in conjunction with the German Brick-Makers' Association, the Berlin Association of Architects, and the association "Berliner Baumarkt," succeeded in laying before the Royal Prussian Bureau of Commerce, Trade and Public Works a set of specifications, which were accepted by said bureau as "Standards for the Uniform Delivery and Testing of Portland Cement." These were issued to the building authorities on November 10th, 1878, for the Kingdom of Prussia, and were later adopted, also, by the remaining German States. From this time the history of the Association, under the guidance of its chairman, Dr. Dellbrück, is identified with the history of the development of the German Portland cement industry, to which development the German manufacturers of machinery and apparatus for Portland cement manufacture, headed by The Iron Works, formerly Nagel & Kämp, of Hamburg, have contributed no small part.

In this epoch of development belongs the first conference, afterwards called the Munich Conference, which was convened in the fall of 1884 by Professor Bauchinger, for the proper utilization of the results of tests made on various materials in different places. The first conference, which was attended by 79 representatives, from Germany,

Hungary, Russia and Switzerland, was soon followed by a second one, held in Dresden, in 1886, and the resolutions there adopted regarding uniform methods of investigation to be pursued in testing the mechanical properties of building and structural materials carried the knowledge of testing methods throughout the world, and awakened interest in those circles which had hitherto abstained from taking part in this matter.

On the strength of these resolutions a revision of the rules was completed in 1886, and these revised rules, after being submitted for opinion to the chief representative of the Royal Prussian Testing Station for Building Materials, Professor Dr. Böhme, as well as the Royal Academy of Architecture, and having been approved by these, with unimportant corrections, were officially promulgated on July 28th, 1887, by the Minister of Public Works for Prussia.

Without a doubt, Germany gained by these means the first rank, from the scientific standpoint of cement technology, among those countries which produce cement in any quantity, and its example has caused other countries to adopt similar action. In Austria, Switzerland and Russia additional rules were later added to the German ones, which at the time deviated in several particulars from the latter, but which at present agree with them on the whole.

In France, England, America, Australia and other countries where cement is largely used, there are no such rigid and comprehensive regulations as the German ones. Certain rules which have gained recognition through tradition and development in the course of time are considered sufficient. The third conference, held in the fall of 1890, in Berlin, which was attended by representatives from all countries, did much to bring the rules enforced in these countries into agreement. Meanwhile the German standards served as laws for the manufacturers, and produced further perfection of the manufactured article, which has been of overwhelming benefit to the public.

The fact that to-day all German factories which belong to the Association turn out a product which, in its principal qualities, never falls below a certain limit amply sufficient for the purposes of the material, is one but rarely found in the extensive manufacture of any article. Viewed from the consumers' standpoint, this is a highly welcome fact, insuring as it does, a guarantee of uniformity of the product at any place and at all times.

It must, however, be well borne in mind that the use of these regulations in no wise guarantees a uniform quality of the product of different factories, or that dependence should be placed upon them without previous tests; but, rather, that while a line of minimum quality has been drawn, no upper limit exists, and it is free to every factory to go as far above the minimum as the various circumstances in regard to location, quality of raw material, etc., permit.

In but one direction did the Association of German Cement Manufacturers deem it incumbent upon itself to go beyond the required regulations and give to the consumer a further, far-reaching guarantee. After the promulgation of the regulations, the practice of mixing different qualities of cement assumed such threatening proportions that the Association, in order to protect the good name of German Portland cement, and at the same time insure construction work against the use of unsound cement, found itself forced to proceed with great vigor against the admixture of all foreign materials to cement. This was done by making the membership of a cement manufacturer dependent on the following declaration, which he was required to sign:

"DECLARATION.

"(*a*) The undersigned members of the Association of German Portland Cement Manufacturers bind themselves to produce under the name of Portland cement only such an article as is made by calcining a thorough mixture, consisting essentially of calcareous and clayey substances, and then grinding the same to the fineness of flour.

"Any article made in a manner differing from the above method, or to which during or after burning any foreign substances have been added, is not recognized by them as Portland cement, and the sale of such products under the designation "Portland cement" is regarded by them as defrauding the purchaser. This declaration does not apply to such minor additions which are made to regulate the setting time of Portland cement, and which are permitted to an extent of 2 per cent.

"(*b*) A member acting contrary to the obligations assumed under *a* shall be disqualified from membership in the Association, and his disqualification shall be made publicly known.

"(c) In making this declaration the undersigned members recognize that the officials of the Association are in duty bound to see that the assumed obligations are adhered to."

In order to give this declaration real significance the association assumed the name "Association of German Portland Cement Manufacturers."

The officials of the Association have, since all members have signed it, made it a point to require that the obligations assumed by the signers are kept. This control, however, can only extend to the possible adulteration during or after burning, and to the raw material out of which Portland cement is to be made. To determine differences in quality of the various brands of Portland cement, a special test remains to be made now, as formerly.

The quality of Portland cement depends first on the combination of the raw materials, and after that on care in manufacture, the proper chemical combination, the degree of burning, the grinding, etc. The properties which are thus given to a particular brand of cement appear especially in the different setting qualities, the power of maintaining a fixed volume, the fineness of the powder and the tensile and compressive strengths; and the testing of these mechanical properties is imperative, in order to form a proper judgment of its qualities.

The remainder of this paper will be devoted to a comprehensive view of the testing methods now prescribed in the German Empire, as well as those in common use beyond the required ones. A description of the apparatus and machinery which has proved itself best adapted to this purpose, and is used chiefly at leading factories, will also be given. Want of space will forbid entering into a description of older or rarely used and unsuccessful apparatus. Tests, also, which require extended chemical knowledge and are incapable of being executed on the site of building by the engineer or architect, in case of need, cannot be considered. In connection with testing methods, it is intended to show, as far as possible from actual examples, the relation of German cement to them, and how the various methods were the actuating cause of a constant improvement of the product.

The regulations for uniform delivery and testing of Portland cement declare it to be a product created by burning to a clinker, a thorough mixture consisting essentially of clay and chalky substances, and then pulverizing the same to the fineness of flour. To regulate

important technical properties, foreign substances not exceeding 2% of the weight may be added without overstepping the regulations.

In the following paragraphs the most important of the regulations are given unchanged, and are in italic.

I. Packing and Weight.—As a rule, Portland cement must be packed in standard barrels containing 180 *kg.* (396 *lbs.*) *gross, and about* 170 *kg.* (370 *lbs.*) *net, and in half barrels of* 90 *kg.* (198 *lbs.*) *gross, and about* 83 *kg.* (183 *lbs.*) *net. The gross weight must be marked on the barrels.*

In case the cement is wanted in barrels of different weight or in sacks, the gross weight must likewise be plainly marked thereon.

Leakage, as well as possible variations in individual cases, are allowable to an extent of 2 *per cent.*

The barrels and sacks, besides the weight, must also be plainly marked with the name or trade-mark of the manufacturing firm.

In the interests of the purchaser and of sound business, the clause relating to an uniform weight is urgently needed.

For this purpose the most commonly used and almost exclusively recognized weight in international commerce of 180 kg. gross (about 400 lbs.) has been chosen.

II. Time of Setting.—According to the purpose for which it is intended, quick or slow setting Portland cement may be demanded. Slow-setting cements are those that set in about two hours or more.

In order to determine the time of setting of a cement, proceed as follows: Make a stiff paste of pure cement and water according to the regulation method, stirring the slow-setting cement three minutes and the quick-setting one minute. On a glass plate make a cake of this paste about 1.5 cm. (0.4 in.) thick, thinning towards the edges, putting all the cement necessary for this end on the plate at once. The consistency of the cement paste should be such that, after having been put on the plate by a spatula, it requires repeated jarring of the plate to cause the paste to thin towards the edges. To this end about 27 to 30% of water is sufficient. As soon as the cake has assumed sufficient hardness to bear the gentle pressure of a finger-nail, the cement is considered as beginning to set.

For an accurate determination of the time of setting and the beginning of the set, which is of importance with quick-setting cements (owing to the fact that cement must be used before it begins to set), it

is best to employ Vicat's regulation needle, endorsed by the Munich Conference and shown in Fig. 1. This needle, of circular cross-section, the end cut at right angles to the axis, having an area of 1 sq. mm. (.002 sq. in.), weighs 300 gr. (about 11 oz.). The tests are made as follows: A ring 4 cm. (1½ ins.) high and 8 cm. (3 ins.) diameter, made of a non-conducting and non-absorbent material, is placed on a glass plate, filled with cement paste of the above-mentioned consistency, and brought under the needle. The moment at which the needle no longer entirely penetrates the cement cake is taken as the "beginning of the set." The time elapsing before the needle ceases to make an impression on the hardened cake is taken as the "time of setting." To determine the proper consistency, let a rod of 1 cm. (0.4 in.) diameter replace the needle, giving a weight of 330 gr. (11.6 oz.). The consistency of the cement paste is to be such that the rod does not entirely pierce it.

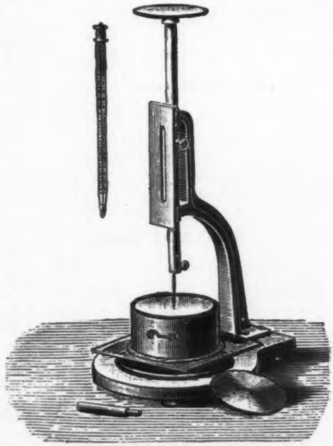


FIG. 1.

Since the setting of cement is influenced by the temperature of the air and water (high temperature hastening, low temperature retarding, it), it is desirable, in order to reach comparable results, to make the tests at a mean temperature of 15 to 18° Cent. Cements generally show a more or less marked rise in temperature while hardening, the maximum being coincident with the beginning of hardening. During the setting, slow-setting cement should not become markedly heated, but quick-setting cement may show a considerable rise of temperature.

Through long storage Portland cement, as a rule, becomes slower setting. It gains in activity if kept in a dry place free from drafts, becoming at first quick setting, and after a few months gradually slow setting. How this varies among different cements is shown in the following table, which is an extract from a complete statement on this point, laid before the General Assembly of the Association

of German Portland Cement Manufacturers on March 24th, 1893, by Dr. Tomëi.

Brand of Cement.	Beginning of time of setting in hours and minutes.								
	Fresh.	Months.							
		1	2	3	4	5	6	9	12
Cement I, in barrel	4.00	3.00	......	0.10	0.30	0.25	1.00	4.30	5.00
Cement I, in sack	5.00	0.15	0.25	1.25	1.00	2.30	2.13	4.00	5.00
Cement I, with ¼% of plaster of paris	5.00	6.00	......	6.00	1.00	0.30	1.22	4.00	5.00
Cement I, with ⅛% of plaster of paris	4.00	4.00	5.00	3.40	3.30	......	4.30	3.45	5 00
Cement II	3.30	.....	0.20	......	......	6.00	......	6.00	4.00
Cement II	2.30	2.15	0.15	0.23	......	2.00			
Cement III	5.00	......	......	0.11	....	4.00	......	4.00	4.00
Cement IV	4.30	5.00	5.30	0.20	0.14	0.18			
Cement V	4.30	4.00	3.00	5.00	5.45	0.40			

The still-prevalent idea that Portland cement deteriorates from long storage is an erroneous one, and all contracts specifying the use of a fresh product only should be discountenanced. The setting qualities of a cement are not only to be considered in its choice for a certain purpose, but also in judging it from the ultimate strength as determined through the regulation testing methods. Of two quick-setting cements, the quicker will be the stronger in 24 hours after hardening, but in 28 days the slower will have the lead. From this point the first begins again to approach the latter and sometimes even passes it. For a mortar of which immediate strength is demanded, or for béton to be used under water, the quick-setting cement should, therefore, always be used; otherwise the slow-setting variety should have the preference, owing to its generally greater strength as well as certainty of maintaining a constant volume.

The quantity of water used in mixing cement has a decided influence in the beginning of the set. To regulate this it is necessary always to bring the mortar to the same consistency. Based on many years of experience, Böhme recommends $(Q\text{-}4)\%$ of water, in which Q denotes the percentage of water necessary to bring the pure cement to the consistency of syrup. The cement paste has the regulation viscosity, measurable by Vicat's apparatus.

III. Constancy of Volume.—The volume of Portland cement should remain constant. The decisive test of this should be that a cake of neat

cement, made on a glass plate, protected from sudden drying and placed under water after 24 hours, should show, even after long submersion, no signs of crumbling, or of cracking at the edges.

In carrying out the regulation test for constant volume the cake made for the purpose of ascertaining the time of setting is placed under water. With a slow-setting cement this is done after 24 hours, and in no case before the beginning of setting. For quick-setting cements only a short time is necessary. It is essential to protect the cakes, especially those of slow-setting cements, from drafts and sunshine until the setting has begun. This is effected by keeping them in a covered box or under moist cloths. The formation of drying cracks is thus avoided.

If crumbling or cracking at the edges appears while the cement is hardening under water, swelling is undoubtedly indicated, *i. e.*, in consequence of an increase in volume a gradual loosening of the bond first formed takes place, and this may lead to a total disintegration of the cement. Indications of swelling generally appear at the end of three days; at any rate, observations extending over 28 days satisfy the regulations. Care must be taken, in making tests for constancy of volume, to distinguish between cracks due to swelling or contracting, and such as are due to a too early submersion of the samples. Since Portland cement naturally increases slightly in volume while hardening under water (which increase rapidly disappears on drying), so-called hair or air cracks may appear as a consequence of repeated change of the cement from a dry to a wet state. These cracks are, however, of detriment to building only when the cement is not properly used. Considerable changes in volume, by swelling of the cement, should, however, be attributed to inferior quality. These changes consist in a considerable expansion which effects a dissolution of the bond previously formed. The swelling takes place after the beginning of setting; the stronger the activity, the earlier the swelling commences. On cement cakes immersed in water it may plainly be seen at the end of a few days in the appearance of a network of fine cracks or, if very marked, in crumbling and cracking of the edges. The cracks around the edges radiate in wedge-shape from the center of the cake. On the contrary, cracks due to shrinkage form irregular curves crossing themselves. Very slow-setting cements are predisposed to such cracking, these forming even at the beginning of setting, especially if

the cement is then exposed to a draft or to sunshine. Cracks caused by putting the cement under water before the beginning of setting should not be confounded with those due to swelling.

One drawback to the method described above lies in the length of time requisite, to shorten which artificial heat has been used to harden the cakes in air instead of allowing them to harden under water. Under this head may be classed the earlier methods from England; the use of balls, according to Heintzel; the test of boiling, according to Michaelis; the steam test of Heintzel, and the lately again-recommended high-pressure test of Erdmenger. The last-mentioned test is the subject of a special paper: "Report on the Investigations Made to Determine the Effect of Magnesium on Portland Cement," by Dr. L. Erdmenger, Hanover, 1893. In North America the hot tests have lately received due attention and been recommended by Mr. W. W. Maclay, M. Am. Soc. C. E.* According to experience in Germany, however, all tests save the German method of cakes are apt to mislead, and we have therefore been obliged always to return to the standard test for constant volume as the most reliable one. In fact this test has caused the occurrence of swelling cements to be of the very greatest rarity in late years. The tests made at the Royal Prussian Station for Testing Building Materials gave the following results:

In the year—	Number of cements tested.	Number not of constant volume.	In the year—	Number of cements tested.	Number not of constant volume.
1879-80	25	0	1885-86	113	1
1880-81	43	0	1886-87	72	
1881-82	83	0	1887-88	103	
1882-83	63	0	1888-89	136	4
1883-84	80	0	1889-90	113	2
1884-85	99	0	1890-91	119	0

Cements of changeable volume differ also in other properties, especially in tensile strength, from the Portland cements, so that they are easily recognized. Although the statement has been made above that the ordinary "swelling cements" may be readily recognized after a few days or at the most weeks of hardening, through the standard tests for constant volume, the cements with a high percentage of magnesia, when burned like Portland cement to a

* "Hot Tests for Determining Change of Volume in Portland Cement." *Transactions* Am. Soc. C. E., Vol. XXVII, p. 412.

slag, seem to form an exception. In such cements swelling appears under water at the end of about a year; in air frequently later, but with increased violence. Mr. R. Dyckerhoff and others have made extensive experiments on this point, employing for this purpose Bauschinger's caliper apparatus. This apparatus, shown in Fig. 2, is employed to advantage wherever it is desirable to follow accurately the

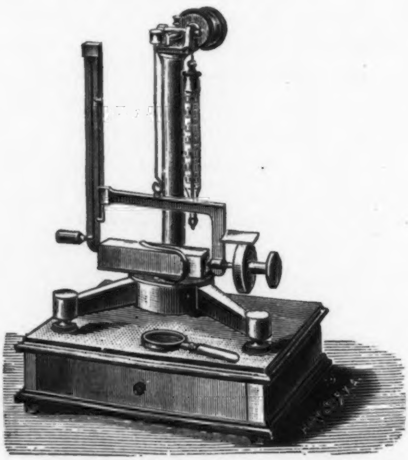


FIG. 2.

expansion or shrinkage of a specimen over an extended period of time. It enables us to determine by direct measurement the changes in length of small parallelopipedons of about 100 mm. (4 ins.) long and 5 sq. cm. (0.78 sq. ins.) area with an accuracy of $\frac{1}{200}$ mm. ($\frac{1}{5000}$ in.). The apparatus consists principally of a stirrup-shaped caliper, having a fine micrometer screw on its right arm, the left being the support of a sensitive lever. The shorter arm of the lever terminates in a blunt caliper point, and is pressed against the measuring screw by a spring attached to the long arm. The calipers are readily moved in any direction, and the micrometer is read in the usual manner. One revolution of the screw equals 0.5 mm. ($\frac{1}{50}$ in.), and readings on the head are made at $\frac{1}{200}$ mm. ($\frac{1}{5000}$ in.). The specimen is placed on a small platform, between the lever and the screw. The points of the calipers are set on center marks drilled into small glass plates let into the specimens.

The width between the caliper points is made equal to 95 mm. (3¾ ins.) in each of these instruments, thus very much simplifying the computations for length. For instance, if the screw reads 9.56 revolutions, the absolute length of the specimen is $\frac{9.56}{2} + 95.00$ mm. $= 99.78$ mm. The specimens are made in small metal frames, just as the standard specimens for tension. It is necessary, however, to turn the moulds over repeatedly, and treat both the upper and under surfaces alike. If this is not done, and the upper surface becomes rather thick and smooth, which a repeated striking off with the trowel will accomplish, it may easily happen that the lower layers remain loose and porous, causing a distortion of the specimen, which may lead to considerable errors. The positions for the center-mark plates are provided for in the forms, and these plates may, therefore, be cemented into place as soon as the specimens are removed from the moulds. To measure a specimen requires but a few minutes, the apparatus being very easy to manipulate.

Long series of experiments have been made in Germany with this apparatus, the results being published in the "Proceedings of the Association of German Portland Cement Manufacturers." An unpublished series of such experiments has been made by the manager of the Portland cement factory "Stern," Dr. Tomëi.

In the following table, F and G are two cements which were tested for tensile strength in a 1:3 mortar, and showed but small strength. It will also be noted that these two inferior brands showed an extraordinary degree of shrinkage, making them unfit for decorative purposes and laying of face stones. This extraordinary shrinkage explains the cracks shown on so many ornamental surfaces, artificial stones and plates, which always have either a neat cement or a mixture low in sand at their surface. The preference for a really good brand of cement for this purpose is thus explained. The table furthermore shows that the commonly accepted theory regarding a uniform relation between expansion when hardening under water and shrinkage when hardening in air is erroneous. The various cements found in the market vary widely in this respect. This much, only, may be said—in general, cements having low compressive strength are liable to great changes in volume when setting in air. Cements not manufactured according to the standards also show great changes in volume.

Portland Cement. Brand.	Hardened in Air.						Hardened in Water.					
	Neat cement.			Normal mixture, 1 to 3.			Neat cement.			Normal mixture, 1 to 3.		
	Time of Hardening, in Days.											
	7	28	90	7	28	90	7	28	90	7	28	90
A. Ground to ordinary fineness	— 0.055	— 0.121	— 0.134	— 0.019	— 0.034	— 0.086	+ 0.021	+ 0.037	+ 0.048	+ 0.006	+ 0.012	+ 0.033
A. Not so finely ground.......	— 0.056	— 0.106	— 0.160	— 0.010	— 0.043	— 0.060	+ 0.027	+ 0.027	+ 0.003	+ 0.012	+ 0.017	+ 0.020
B..........................	— 0.101	— 0.188	— 0.260	— 0.025	— 0.074	— 0.123	+ 0.003	+ 0.013	+ 0.010	+ 0.005	+ 0.033	+ 0.035
C..........................	— 0.075	— 0.118	— 0.175	— 0.015	— 0.020	— 0.068	+ 0.005	+ 0.020	+ 0.010	+ 0.030	+ 0.005	+ 0.030
D..........................	— 0.055	— 0.125	— 0.185	— 0.015	— 0.073	— 0.090	+ 0.005	+ 0.012	+ 0.019	+ 0.005	+ 0.010	+ 0.005
E..........................	— 0.045	— 0.120	— 0.175	— 0.023	— 0.075	— 0.110	+ 0.027	+ 0.048	+ 0.035	+ 0.007	+ 0.035	+ 0.043
F..........................	— 0.117	— 0.252	— 0.321	— 0.032	— 0.072	— 0.120	+ 0.035	+ 0.035	+ 0.053	+ 0.015	+ 0.020	+ 0.019
G..........................	— 0.125	— 0.234	....	— 0.045	— 0.058	....	+ 0.025	+ 0.035	....	+ 0.013	+ 0.020	....

For the sake of illustration a number of such cements, used by R. Dyckerhoff, Amöneburg, to test the effect of magnesium, have been noted (Fig. 3). In passing it may be mentioned that Dyckerhoff, in agreement with Prof. Débray, of the École des Ponts et Chaussées, Paris, Dr. Erdmenger and others, found a heightened tendency to

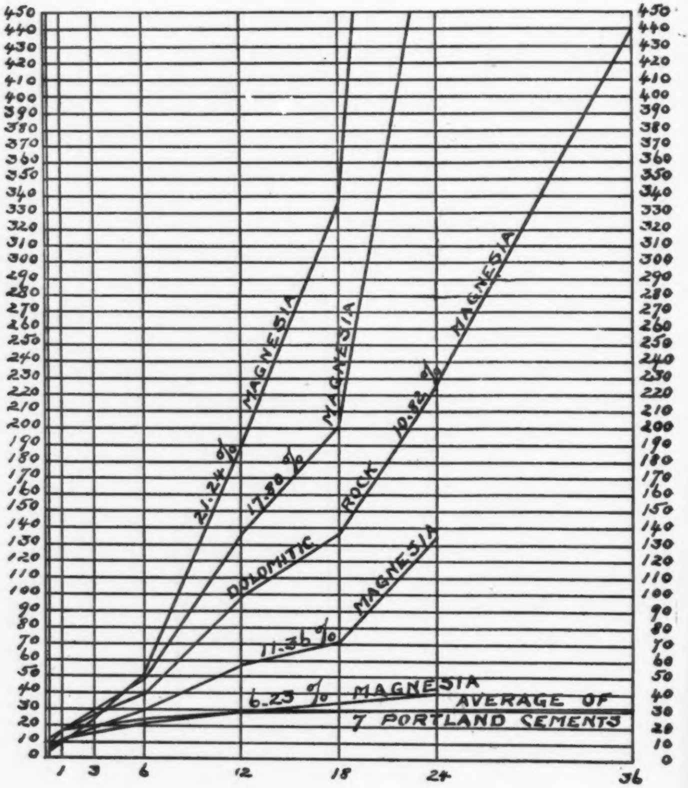


FIG. 3.

swelling (variable volume) in cements containing much magnesia, and also that the maximum amount of magnesia a cement may safely contain is not yet determined. In Germany a special commission is still engaged in further detailed investigations. It is, however, certain

that a cement may contain as high as 5% of magnesia without causing apprehension as to its qualities.

IV. Fineness of Grinding.—Portland cement must be ground so fine that no more than 10% *of a sample shall pass through a sieve of* 900 *meshes* / fail to *per square centimeter* (5 800 *per square inch*). *The thickness of the wires of the sieve to be one-half the width of the meshes.*

The quantity of cement to be used for this test is 100 gr. (3.2 oz.). Since cement is frequently used with a high percentage of sand, and the strength of mortar increases with the fineness of the cement used (because then more parts of the cement come into action), the fineness of cement is of a high value. It therefore seems desirable to test the fineness of the grain in a uniform manner by means of a sieve of the gauge given above. In Germany, brass-wire sieves having 180, 324, 600, 900, 4 900 and 5 000 meshes, respectively, per square centimeter are used (1 200, 2 200, 3 800, 5 800, 31 000 and 32 000 meshes per square inch). The sieve of 900 meshes is, according to the regulations, the standard.

It would be fallacious to decide from the fineness alone of a cement as to its quality, since inferior, soft cements are much oftener found finely ground than well burned. Well-burned cements will show a higher strength, as a rule, even if not so well ground as those poorly burned. If the cement is to be used mixed with lime, it is best to employ a well-burned and finely ground quality, the increased cost of which is counterbalanced by a marked improvement of the mortar. Since a well-burned, finely ground cement possesses a greater value, it is easily seen why the manufacturers have aimed to attain a high degree of fineness, while maintaining a high specific gravity. The following table will show to what extent the perfecting of old and the introduction of new mill machinery have produced the desired end. From it also appears how the cements tested at the Royal Prussian Testing Station for Building Materials approached the standards more nearly as the years went by. Only isolated cases of cements leaving more that 20% on the sieve of 900 meshes occur in the 12 years given in the table. Cements leaving between 20 and 10% have increased in number since 1882, and in the last few years very decidedly, while the very fine ones leaving less than 10% have increased proportionately. This increase is especially marked since 1887, the year of introducing the new standards, and shows that suc-

cess has not failed to crown the efforts of the German cement manufacturers to perfect their product. The year 1890–91 did not show a single one of the 119 samples of cement tested, both officially and privately, to fall short of the requirements of the regulations regarding fineness.

Fineness of German Portland Cement.

Cements Tested.		Above 20 per cent.		Between 20 and 10 per cent.		Below 10 per cent.	
		Failing to pass through 900-mesh sieve.					
Years.	Number.	Number of cements.	Percent.	Number of cements.	Percent.	Number of cements.	Percent.
1879–80	25	2	8.0	13	52.0	10	40.0
1880–81	43	....	....	6	14.0	37	86.0
1881–82	84	1	1.2	29	34.9	53	63.9
1882–83	63	1	1.6	25	39.7	37	58.7
1883–84	80	4	5.0	26	32.5	50	62.5
1884–85	98	3	3.1	39	39.8	56	57.1
1885–86	115	....	....	37	32.2	78	67.8
1886–87	72	1	1.4	16	22.2	55	76.4
1887–88	105	3	2.9	13	12.4	89	84.8
1888–89	146	....	....	3	2.0	143	98.0
1889–90	113	....	....	3	2.7	110	97.3
1890–91	119	....	....	....	....	119	100.0

V. Tests for Strength.—The binding strength of Portland cement is to be determined by testing a mixture of cement and sand. The test is to be conducted for tensile and compressive strength according to a uniform method, and is to be performed upon test specimens of like form, like cross-section, and with like apparatus. It is recommended, besides, to determine the strength of neat cement.

The tests for tension are to be made upon briquettes of 5 *sq. cm.* (0.78 *sq. in.*) *cross-section at the place of rupture, the tests for compression upon cubes of* 50 *sq. cm.* (7.8 *sq. ins.*) *area.*

Since experience has shown that the results for tensile strength obtained from neat cements do not give uniform conclusions regarding the binding properties of the cement and sand, especially where brands from different factories are under comparison, it is recommended to test the binding strength of Portland cement by means of a sand mixture. The testing of cement without sand is to be especially recommended if a comparison of Portland cement is to be made with mixed

cements and other hydraulic binding mixtures. In this way the superiority of Portland cement, owing to certain qualities which are wanting in the other hydraulic binding materials, is better brought out than when tested as a sand mixture.

Although the relation of compressive to tensile strength is a varying one among hydraulic cements, yet the test for tensile strength is frequently the only one used in comparison of different kinds. This, however, leads to an erroneous judgment of them.

And further, since in practice mortar is chiefly called upon to withstand pressure, the standard test of strength should be no other than the test for compression. In order to maintain uniformity in these tests the German regulations recommend the use of such apparatus and tools as are employed at the Royal Testing Station at Charlottenburg, Berlin. These instruments will be further described below.

VI. Tensile and Compressive Strength.—Slow-setting Portland cement, when mixed with standard sand in the proportion of 1 *part of cement to* 3 *of sand by weight,* 28 *days after being mixed—one day in air and* 27 *in water—must possess a tensile strength of not less than* 16 *kg. per square centimeter* (225 *lbs. per square inch*), *and a maximum compressive strength of* 160 *kg. per square centimeter* (2 250 *lbs. per square inch*).

Quick-setting cements generally show a lower strength after 28 *days than that given above. The time of setting must, therefore, be given when stating figures relative to strength.*

When comparing several varieties of cement it is absolutely necessary to make a test with a high percentage of sand, because the setting properties of different varieties vary much with the amount of sand. A proportion of 1 part cement to 3 of sand by weight is taken as a standard, for with 3 parts of sand the binding qualities of a cement are sufficiently tested.

A cement which shows a higher tensile or compressive strength often allows a larger percentage of sand, and, on this account, as well as owing to greater strength with the same amount of sand, can fairly command a higher price.

The standard-strength test is that for compression after an interval of 28 days. In a shorter period the time of setting is not sufficiently emphasized. The results may, for instance, show an equal strength for different cements after 28 days, while at the end of but seven days there would be a marked difference.

The tensile strength, after 28 days, serves as the usual test of the furnished product. Should it, however, be desirable to make a test at the end of seven days, the relation of the tensile strength after seven days to that at the end of 28 days must first be determined. This test may also be made with neat cement, if the relation of the strength of cement to that with 3 parts sand and 28 days old has been determined. It is recommended that, whenever possible, the tests be extended over some time, the briquettes being made and kept for this purpose, in order to determine the behavior of different cements after a longer period of hardening.

The standard sand used at the Royal Testing Station in Berlin is produced by washing and drying quartz sand which must be as clean as possible, and afterwards be sifted through a sieve of 60 meshes per square centimeter (387 meshes per square inch), by which process the coarser particles are separated. The sand is again sifted through a sieve having 120 meshes to the square centimeter (774 per square inch). The residue remaining in this sieve is the "standard sand" for experiments, the coarsest and finest particles having been eliminated. It is absolutely necessary, in order to obtain uniform results, to use only the standard sand described above, as the size of grain of the sand has a material influence on the results of the testing. The standard sand must be clean and dry, and all earthy and other substances be previously removed by washing.

The Prussian sand is obtained near Freienwalde on the Oder, in the province of Brandenburg, and may be had sifted and washed from the Chemical Laboratory for Clay Industry, No. 6 Kruppstrasse, Berlin.

Since all quartz sand does not give the same strength even if uniformly handled, it becomes necessary to ascertain if the sand at disposal is up to the standard furnished under direction of the management of the "Association of German Cement Manufacturers," which is the standard used at the Royal Testing Station at Berlin. Sand possessing the standard qualifications is found in various parts of Germany. An international standard sand has not yet been adopted, and it is on this account that tests made on Portland cement give different results in different countries. The Russian standard sand, for instance, gives markedly lower, and the Swiss sand considerably higher, strength than the German.

In order to avoid the variation produced in the sand by the gradual

change in sieves of wire netting, due to wear, the last conference for the unification of testing methods, held in Berlin, 1890, decided to substitute for the wire sieves others of tin, the openings being circular. A commission was appointed to fix the size of the holes and their arrangement, as well as the thickness of the tin. The new sieves must separate a sand which shall possess a tensile strength equal to that furnished by the present standard sand. It is expected that a decision will be reached on this point at the conference to be held in Vienna in 1893.

Tensile Tests.

(*a*) *Handwork.*—On a slab of metal or marble are laid 10 small sheets of filtering paper, which have been previously saturated with water, and upon these are placed 10 brass moulds, thoroughly clean and moistened with water, 250 gr. of cement and 750 gr. of dry standard sand are thoroughly mixed, and to this is added the requisite quantity of water as specified by weight, in the most cases 10% = 100 gr. The whole mass is then worked up with a trowel or spatula until it exhibits an appearance of perfect homogeneity. In this manner a very stiff mortar is obtained, which has the appearance of freshly dug moist earth. With this mortar the 10 moulds are filled and heaped up; the mortar is then beaten into the moulds with an iron trowel (of from 250 gr. (=10) to 13 ozs. weight), at first lightly and afterwards more heavily, until it becomes elastic and water appears on the surface (such a trowel is pictured in Fig. 5). It is of the utmost importance that the blows be kept up uninterruptedly until this point be attained. The superfluous mortar is now scraped off with a knife, and by means of the same the surface is leveled. By using greater force a larger quantity of mortar than specified above might be hammered into the moulds, and the briquettes gain in tensile strength accordingly; this would, however, be against the regulations for the uniform delivery and testing of Portland cement.

When the briquettes have become sufficiently hard, they are taken out of the moulds by undoing the screws, and any adhering filtering paper is removed. After remaining 24 hours exposed to the air, at a temperature of about 60° Fahr. and in a covered box, the briquettes are immersed in water having the same temperature, and care must be taken that they remain covered with water until the time arrives for taking them out. On the day of testing the briquettes are taken from

the water and immediately broken on the machine. The average of 10 breaking weights furnishes the strength of the mortar tested.

(*b*) *Machine Work.*—The specimens are to be made with the hammer apparatus of Dr. Böhme, and the hammer of 2 kg. ($4\frac{1}{2}$ lbs.) weight is

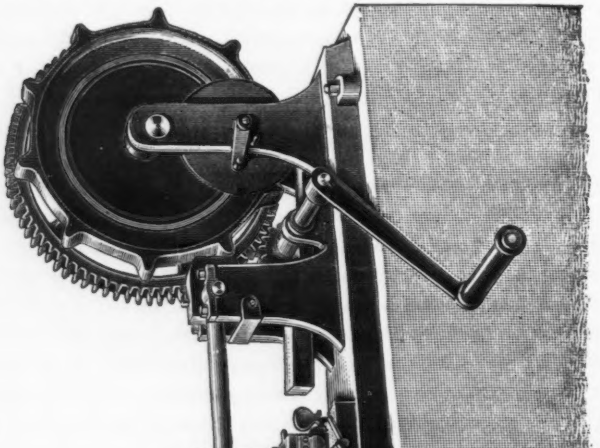


FIG. 4.

to deliver 150 blows upon the mould. If the prescribed directions are closely followed the results obtained from machine and hand made specimens agree well.

For a disputed case, however, the machine-made specimens are to be considered the standard. Böhme's hammer apparatus (Fig. 4) is a tilt hammer with automatic action.

The hammer is driven by a cam wheel of 10 cams actuated by a simple gearing. The wrought-iron handle of the hammer is let into the cross-head which carries the axle of the hammer and keyed to this cross-head and to the cap, so that it may be readily replaced if worn. The steel hammer of 2 kg. (4½ lbs.) is similarly fastened to the cap. As soon as the intended number of blows has been delivered, the mechanism is automatically checked, the proper setting having been made for this purpose before beginning the work.

The forms to receive the mortar (which are shown separated and together for tensile and compression specimens in Fig. 4) consist of a lower and upper case held together by means of springs. The lower case for compression specimens consists of two angle irons held on a planed plate by a grinding strip and a screw acting on the latter. Upward motion is prevented by two wedge-shaped surfaces. The lower case and half of the upper one is filled with the mortar to be tested, and a plate laid upon its surface. On this plate the blows are delivered. It is of vital importance that the apparatus rest on a firm non-elastic foundation, preferably it should be placed and fastened on a pier of masonry.

Compression Tests.—In order to have tests for compression made at different places give results in agreement with each other, it is necessary to make the specimens by machinery.

Take 400 gr. (14 ozs.) of cement and 1 200 gr. (42.2 ozs.) of dry standard sand, mix thoroughly in a dish, add 160 gr. (3.6 ozs.) of water, and work the resulting mortar thoroughly for five minutes (quick-setting cements are to be worked but one minute). Put 860 gr. (30.3 ozs.) of this mortar into the cubic mould properly provided with filling cases and fastened to the bed plate. The iron core is placed into the form, and 150 blows are delivered on it by means of the hammer apparatus, with the hammer of 2 kg. (4½ lbs.) weight. The filling cases and core having been removed, the specimen is struck off and flush, smoothed and drawn off the bed-plate together with the mould.

For neat cement specimens mix about 1 000 gr. (2.2 lbs.) cement with the requisite amount of water, and proceed as in *a*. The moulds

should be oiled a little, and can be removed only after the cement has sufficiently hardened.

There are no fixed directions in the regulations regarding the time the test specimens are to remain in the moulds, but it has been agreed that specimens for compression, as well as hand-made tensile specimens, are to be removed only after the mortar has well set, *i. e.*, from 20 to 24 hours after being made. Tensile specimens, machine made, may be at once taken from the moulds, since they are somewhat harder. The amount of water used is always to be mentioned when giving figures regarding strength.

Method of Making the Test.—All specimens are tested as soon as taken out of water. In tensile tests the increase in tension is to be made at the rate of 100 gr. (3.5 ozs.) per second, since the time occupied in making the tests is of importance.

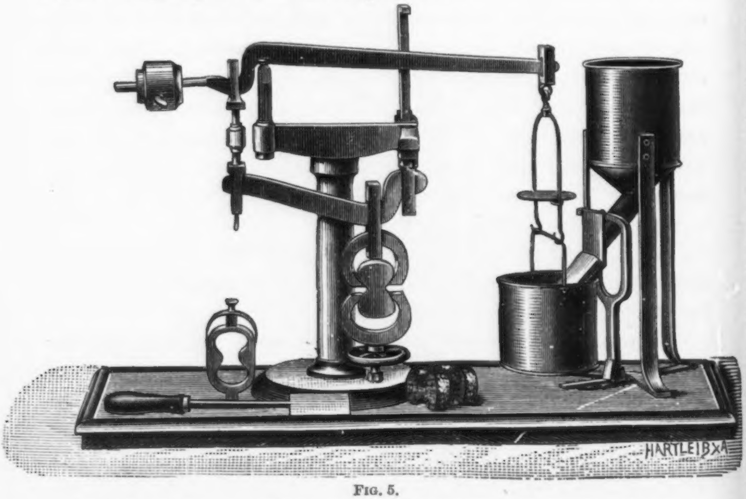


FIG. 5.

In order to insure uniform results, the pressure in compression tests is to be applied to the sides of the cube, and not to the bottom or to the top surface which has been worked. The mean of every 10 tests is taken, according to the regulations, as a measure of the strength, which? which the resolutions of the Munich Conference prescribe every six specimens, of which the arithmetic mean of the highest four is taken as the measure of strength. Dr. W. Michaelis' double-lever automatic

cement-testing machine is the one universally employed in Germany for making tensile tests. This machine is shown in Fig. 5.

Upon a massive pillar, about $\frac{1}{3}$ m. in height, are fastened two levers connected with one another; the upper has a leverage of 10 to 1, the lower of 5 to 1. To the latter is fastened the upper clip; the lower clip is attached by means of a ball joint to a screw, with a hand-wheel for raising or lowering. The clips are constructed on the most scientific principles and insure the strain being brought to bear on the briquette in the most favorable manner. There is also a counter balance for bringing the levers into exact equilibrium. At the time of testing the briquettes are taken directly from the water and set up on edges to drip. The lower clip is then raised by means of the wheel, and the briquette is placed in position. The adjustment of the levers is now effected by means of the wheel. In adjusting the briquette, care should be taken that the upper clip is exactly over the under one, and that their ends are horizontal and parallel; and that, after attaching the bucket for receiving the breaking weight, this latter should remain suspended 5 to 10 cm. above the level of the table. The vessel for the delivery of the shot is provided with a trap, which cuts off the stream of shot instantaneously. The shot is allowed to pour out by opening the trap.

At the moment the fracture occurs, the stream of shot instantly ceases. The bucket is now removed and weighed on a spring scale. The lever proportion is that of 50 to 1, and the section of the briquette 5 sq. cm.; the weight employed is, therefore, $\frac{5}{50}$ of the actual breaking strain; the number indicated in the scale has thus to be multiplied by 10. Although the apparatus itself can be made to serve for ascertaining the weight employed in fracturing the briquette, the use of a spring scale is recommended, on account of the saving in time it effects, and because, thereby, a direct reading is possible. If it be desired to ascertain the breaking weight by means of the apparatus itself, the bucket, with the shot, is suspended from the hook, which will be found under the connecting piece, between the two levers; the upper one of these is brought into equilibrium by placing weights in the pan at the farther end. The breaking weight employed is thus again weighed decimally, the number of grams required to counterbalance it representing $\frac{1}{100}$ of the actual breaking strain per sectional unit; the actual breaking weight

in kilograms per square centimeter is obtained by simply cutting off the last place from the number of grams (placing the decimal point before the last figure). In order to test accurately very weak briquettes it is sufficient to place 10 to 20 grains of shot in the bucket, that the clips may grip the briquette. The remainder of the weight is then added in the form either of fine shot or pounded quartz, dropped in from the hand or from a vessel with a spout supplied for the purpose. The weight is best ascertained by means of a small hand balance; the weight indicated must be multiplied by 10, as above stated.

Testing by Compression.—Portland cement ceases to grow in tensile strength after some years; its elasticity decreases while its compressive resistance increases; it becomes like a piece of pottery, and should then be tested by compression. If it be remembered that in order to crush a cube of only 50 sq. cm. a great weight is necessary, it will be obvious that only powerful presses can be used.

Figs. 6 and 7 illustrate a machine for testing the compressive resistance of cement. This machine is a hydraulic press, the pressure of whose liquid is so far reduced by a system of pistons that it can be easily measured by the pressure of a column of quicksilver of convenient height. In Fig 6 *A* is the piston causing the pressure, *B* and *C* are the pistons to reduce the pressure of *A*, *D* is the quicksilver manometer, the chief part of which is a glass tube open at the top, standing at the bottom in connection with the space under the piston *C*. The cube *E* lies between the two plates *F* and *G*, of which the first rests with a spherical surface on the piston *A* and can place itself in the proper position. The upper plate *G* hangs to the lower end of the screw *H*, and can be raised to a convenient height by means of a hand wheel. The cylinder *K*, in which the piston *A* moves, is filled with castor oil. If the piston-rod *L* is pressed into the cylinder *K*, a pressure is exerted on the fluid, and thereby the piston *A* lifted and the thin piston *B* driven downward. The piston *B* presses on the larger piston *C*, and this again exerts a pressure on the liquid underneath. This liquid consists of a layer of castor oil under the piston *C*, having only the purpose to render the piston air tight. Under the castor oil is quicksilver that fills the lower part of the cylinder *M* and the connection of the quicksilver manometer. In consequence of the pressure on the liquid under the piston *C*, the quicksilver rises in

the glass tube till the column balances the pressure. On the scale-board to the right of the glass tube the total pressure of the piston *A*

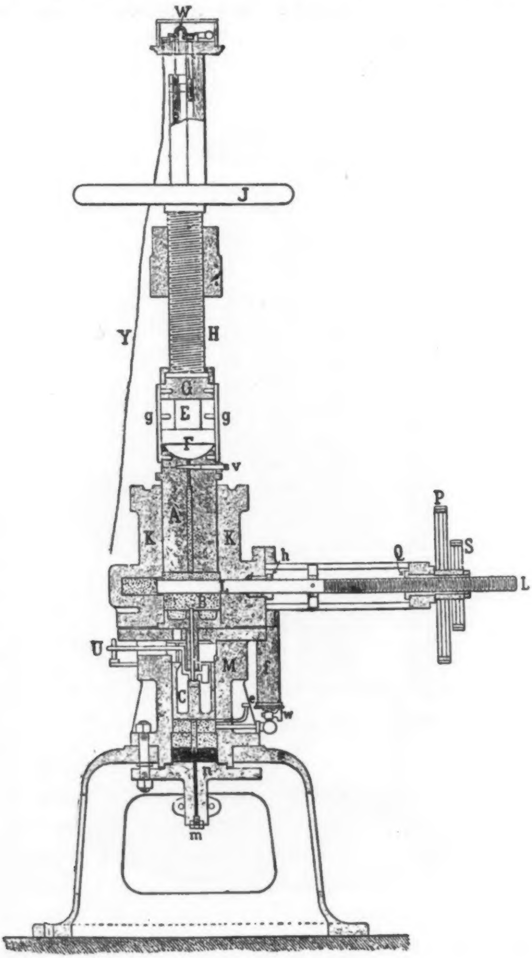


FIG. 6.

is read in tons (1 ton = 1 000 kg.); on the scale-board to the left of the glass tube the pressure exercised on 1 sq. cm. of the surface of a

normal cube (50 sq. cm.) is read in kilograms (instead of this the pressure of the liquid under *A* could be read in kilograms per square centimeter or in atmospheres). The maximum pressure of 30 000

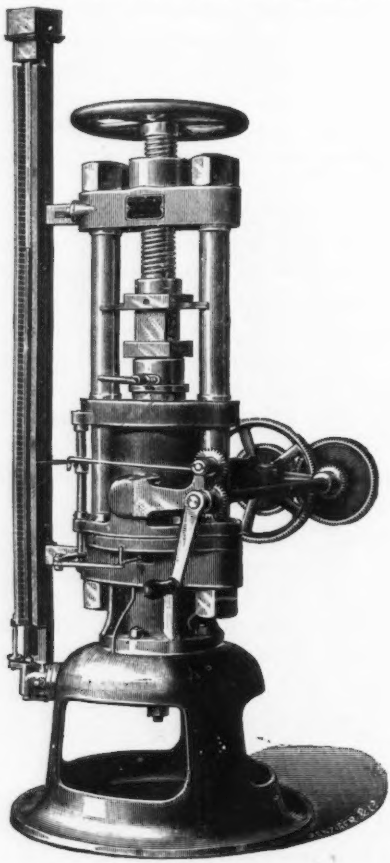


FIG. 7.

kg. on the piston *A* is equal to a height of the quicksilver column of about 140 cm.

A cheaper grade of the same apparatus is made in a slightly different form, but such accurate results cannot be obtained with it.

The upper plate of this apparatus shown in Figs. 8, 9 and 10 is rigid, and only the under one is attached by a ball and socket joint to the piston. The provision for measuring the intensity of the pressure is as follows: The large pressure cylinder *A* has hydraulic connection with a manometer *C* by means of a pipe *B*. This manometer consists simply of a thin piston, ground to fit, its upper end pressing against a plate and thereby tending to elongate a spring. The elongation of the spring is, therefore, proportional to the pressure existing in the large cylinder and consequently proportional to the pressure exerted on the cube of cement. This pressure may be read on a disc with two

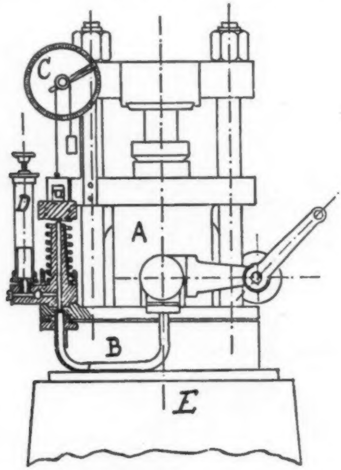


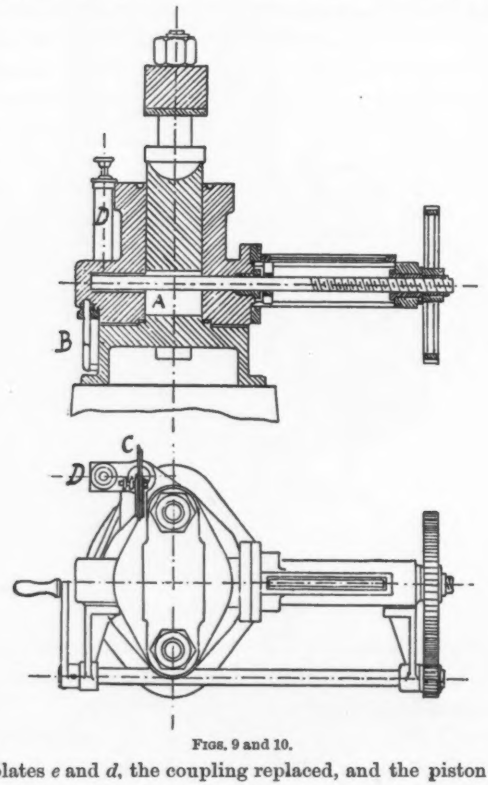
FIG. 8.

indices. The one is moved by a cord from the spring, while the other is carried along by the first, and remains wherever it happens to be when the specimen fails.

The press is driven by means of a crank, just as in the one previously described; but, to simplify, the construction, the device for the quick return of the pressure rod has been omitted. A hand pump *D* and a cock serve to raise and lower the under plate rapidly. A controlling lever, which may be removed when the apparatus is in use, serves to place the index in the proper position by means of directly attached weights.

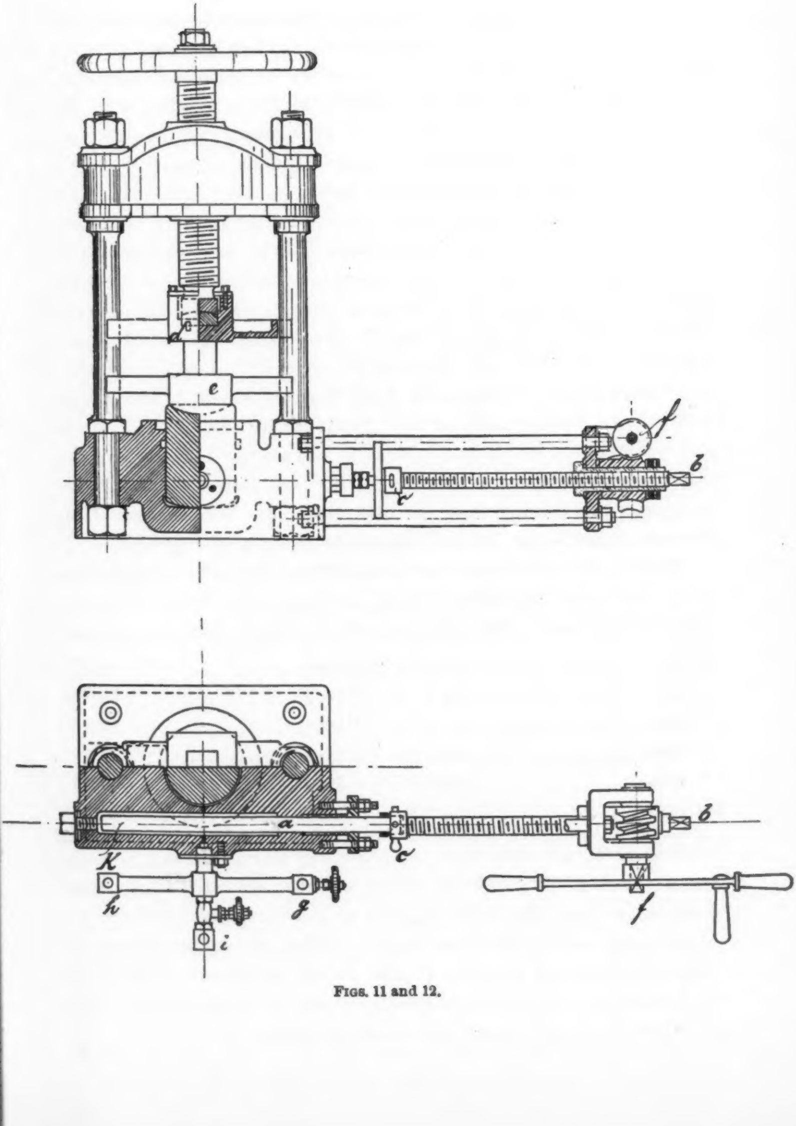
To test higher strengths, recourse must be had to a hydraulic press with metal manometer, such as are used for the most varied industrial purposes. Its construction is shown in Figs. 11 and 12.

The method of working this machine is as follows: The crank is put on at *b*, the coupling pin *c* removed and the piston *a* unscrewed completely. The body to be tested is then placed between the ball-



FIGS. 9 and 10.

bearing plates *e* and *d*, the coupling replaced, and the piston *a* turned by means of the crank placed at *f*, until the index of the manometer *g* or *h*, by remaining stationary or moving backwards, shows that failure of the test specimen has begun. The low pressure manometer *g* is to be kept closed if it is intended to use a higher pressure. The check manometer *i* is opened only by means of a check cock at *h*. The



Figs. 11 and 12.

press is filled with glycerine which may be introduced above the piston *a* at about *K*.

The press described as the standard Swiss apparatus leaves nothing to be desired in accuracy of measurement. In this ring packing is not needed, and the piston friction is annulled by the use of castor oil. Lately another machine has been built by Engineer Suchier, of Frankfort-on-the-Main, which allows tests of tension, compression and adhesion. This is operated by oil under hydraulic pressure.

The perfection of cement-testing machines was the natural consequence of the altered development which the manufacture of cement in Germany took after the promulgation of the new standards, and which laid greater and greater importance on the highest possible compressive strength. The following tables give the experiments of the Royal Testing Station at Berlin. Considering the recent experiments in connection with those made since 1879 a very instructive comparison of the development of the German cement industry with reference to the strength of the product, particularly in tension and compression, is obtained. Mention has already been made of the improvement in regard to fineness. While the tests for compression were only occasionally made in 1883, they have become, since 1887, the most important factor for judging the qualities of cements.

Table A shows that cements having a tensile strength of more than 15 kg. per square centimeter (215 lbs. per square inch) form the greater part of those tested. The percentage of such for the different years was:

In 1880	68.2 %	In 1886	80.7 %
" 1881	94.7 "	" 1887	80.9 "
" 1882	88.3 "	" 1888	73.8 "
" 1883	59.7 "	" 1889	77.4 "
" 1884	84.8 "	" 1890	72.7 "
" 1885	74.2 "	" 1891	85.7 "

It is seen that from 1886 to 1890 there was no increase, perhaps because during this period the effort was made to reach the specified compressive strength of 160 kg. per square centimeter (2 300 lbs. per square inch) with a tensile strength of 16 kg. per square centimeter. But if the cements between 15 and 16 kg. per square centimeter in tensile strength should be counted, probably the years 1888–90 would not have lower percentages than those preceding.

RESULTS OF TESTS OF PORTLAND CEMENTS MADE IN THE ROYAL TESTING STATION FOR BUILDING MATERIALS AT BERLIN.

A. TENSILE STRENGTH ACCORDING TO STANDARDS OF NOVEMBER 10TH, 1878.

Year of tests.	Number of 28-day tests.	Tensile strength in kilograms per square centimeter.									
		Below 10.		Between—						Above 30.	
				10 and 15.		15 and 20.		20 and 30.			
		Number.	Percent.	Number.	Percent.	Number.	Percent.	Number.	Percent.	Number.	Percent.
1879-80...	22	...	....	7	31.8	1	4.6	13	59.1	1	4.6
1880-81...	38	1	2.6	1	2.6	13	34.2	19	50.0	4	10.5
1881-82...	77	3	3.9	6	7.8	39	50.7	25	32.5	4	5.2
1882-83 ..	57	5	8.8	18	31.6	21	36.8	11	19.3	2	3.5
1883-84...	79	2	2.5	10	12.7	27	34.2	39	49.4	1	1.3
1884-85...	89	2	2.3	21	23.6	33	37.1	33	37.1	...	....
1885-86 ..	109	2	1.8	18	16.5	37	33.9	41	37.6	10	9.2
1886-87...	68	...	....	12	17.7	20	29.4	31	45.6	4	5.9

B. TENSILE STRENGTH ACCORDING TO STANDARDS OF JULY 28TH, 1887.

Year of tests.	Number of 28-day tests.	Tensile strength in kilograms per square centimeter.					
		Below 16.		Between 16 and 20.		Above 20.	
		Number.	Percent.	Number.	Percent.	Number.	Percent.
1887-88............	103	29	28.2	32	33.0	42	40.8
1888-89............	137	31	22.6	59	43.1	47	34.3
1889-90............	99	27	27.3	38	38.4	34	34.3
1890-91............	112	16	14.3	43	38.4	53	47.3

C. COMPRESSIVE STRENGTH ACCORDING TO STANDARDS OF JULY 28TH, 1887.

Year of tests.	Number of 28-day tests.	Below 160 kg. per square centimeter.		Between 160 and 200 kg. per square centimeter.		Above 200 kg. per square centimeter.	
		Number.	Percent.	Number.	Percent.	Number.	Percent.
1883-84............	21	15	71.4	5	23.8	1	4.8
1884-85............	29	12	41.4	7	24.1	10	34.5
1885-86............	26	9	34.6	4	15.4	13	50.0
1886 87............	22	7	31.8	6	27.3	9	40.9
1887-88............	53	30	56.6	13	24.6	10	18.9
1888-89............	121	50	41.3	38	31.4	33	27.3
1889-90............	84	16	19.0	25	29.8	43	51.2
1890-91............	85	28	33.0	26	30.6	31	36.5

The endeavor to secure a high compressive strength is plainly seen in the last table, the number of those below the standard continually decreasing, while those between 160 and 200 kg. per square centimeter (2 300 and 2 900 lbs. per square inch) slightly increase, and those above 200 kg. per square centimeter materially increase, in number.

If we cast a retrospective glance over what has been already said regarding the standard methods of testing of Portland cements, it will be apparent that impartial testing is not an easy thing, and that a certain training is necessary in order to observe the different regulations and secure trustworthy results. Accordingly, at the request of the Association of German Portland Cement Manufacturers, the Royal Testing Station for Building Materials at Charlottenburg, near Berlin, was designated by the Minister of Public Works of Prussia, by a decree of August 16th, 1880, as the authority for settling technical questions in dispute. At the same time it was ordered that in contentions between sellers of cement and the Bureau of Public Works concerning the quality of cement, the decision of this testing station, made after proper tests, should be final and binding upon both parties with respect to all technical points.

Although the standard tests are entirely satisfactory for these purposes and for the comparison of specimens, yet they are not sufficient to completely define all the properties of a good Portland cement, and its special qualities for special purposes. Hence, in Germany, methods of testing—apart from the standards—have become further developed, and there are several in use which cannot be passed over in silence, since the international commission above mentioned has approved and recommended them.

Weight may be mentioned as an important distinctive element. To determine this, cement may be allowed to fall from a sieve into a liter measure, which is then shaken. The apparatus of Tetmajer was recommended for this purpose by the commission of September 20th, 1890, but it has not yet come into use in Germany. The determination of the specific gravity of the cement particles by the volume-meter of Schumann is a well-known uniform method. This consists of a glass bottle of about 200 cu. cm. (12.2 cu. ins.) capacity, with a calibrated glass tube in its neck. The bottle is nearly filled with oil of turpentine, the tube tightly inserted and filled by a pipette with the same oil to the zero mark of the scale, care being taken that all air bubbles

are removed. One hundred gr. (3.5 ozs.) of cement is put in through the tube, which is then closed by a cork. When the fluid becomes clear, the height of its top surface is noted on the scale. The weight of the cement divided by its volume, as determined by the scale of readings, gives the specific gravity. To secure precise results, it is necessary that the temperature should remain uniform throughout the experiment, and hence vessels, cement and oil must have been kept in the same room for some considerable time. In hot weather the apparatus can be put into water of a known constant temperature. If 100 gr. of cement are used, a rise of 1° Cent. between the two readings decreases the specific gravity 0.8 per cent.

The specific gravity of fresh Portland cement varies, according to the brand and the proportion of lime, between 3.12 and 3.25. Stored cement becomes heavier by absorption of water and carbonic acid from the air; but this can be almost restored to the original condition by reheating. The specific gravity affords the only means of determining the calcination of a cement with certainty, and is hence of high value.

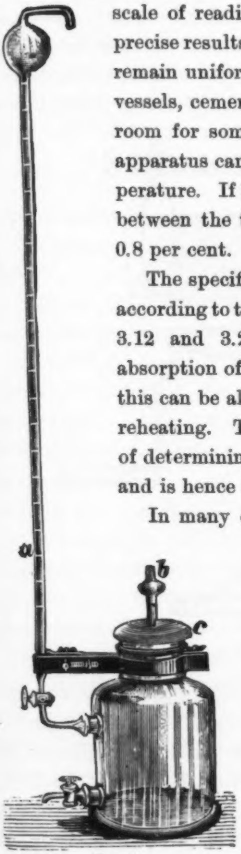


FIG. 13.

In many cases it is of importance to know whether the briquettes tested for tension and compression were prepared of uniform density, and this can only be ascertained through the specific gravity. For this purpose Seger's volume-meter can be used. This is a glass vessel with two tubes inserted in one side, provided with a cap *c*, which is funnel-shaped on top, so that no air bubbles can long be retained, and which has a tube *b*, where a zero point is marked. The tube *a* is provided with an outlet cock below and with a ball on top of about 100 cu. cm. (6.1 cu. ins.) capacity. The lowest tube is merely an outlet cock. The apparatus is filled with water, air bubbles being avoided, up to the zero mark on both the tubes *a* and *b*. Then the water is drawn up into the ball of the tube, the outlet cock opened, the speci-

men placed in the water, and the water again allowed to rise to the zero mark. The height of water in the tube then shows the volume of the briquette, and the specific gravity is the ratio of its weight to its volume. Finally, there is one more method of testing to be mentioned which has been repeatedly used at the Berlin Testing Station, as well as by Professor Bauschinger, of Munich, and which seems capable of giving valuable information regarding the binding properties of cement. This is the test for wearing qualities of cement (Fig. 14).

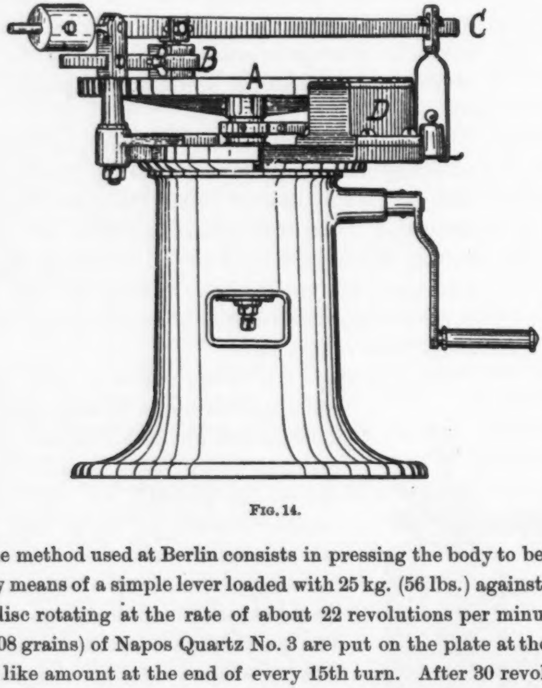


FIG. 14.

The method used at Berlin consists in pressing the body to be tested (*B*) by means of a simple lever loaded with 25 kg. (56 lbs.) against a cast-iron disc rotating at the rate of about 22 revolutions per minute; 20 gr. (308 grains) of Napos Quartz No. 3 are put on the plate at the start, and a like amount at the end of every 15th turn. After 30 revolutions of the disc the body, which was weighed before starting, is again weighed and the loss determined. The revolutions are automatically registered at *D*.

When making the tests, cubes 1 cm. in size are made with the regulation hammer apparatus, after the usual manner of making specimens to be tested for compression. After hardening 7 or 28 days in air or under

water they are weighed. By means of Seger's volume-meter, the density is next determined and the body then subjected to the above-described friction process. The quantity lost in this test is shown by the expression $\frac{g - g_1}{g : v} = v\ 7$ (for a seven days' specimen, in which g and g_1 are the first and last weights and v the volume. The same specimens are used for the 28 days' tests, but the density must be determined anew just before beginning the test, since the weight of the specimens alters under the influence of air and water. The density after 28 days is $v\ 28 = \frac{g\ 28}{v_1}$ in which $g\ 28$ is the weight of the specimen just before beginning the 28 days' test, and $v_1 = V - v\ 7$, or the original volume V diminished by the amount in cubic centimeters lost in seven days ($v\ 7$).

For the 28 days' test divide the weight lost by friction by $V\ 28$, to obtain the quantity $v\ 28$.

In order to compare the amount of loss sustained by different cements and mortars, the results of experiments made at six different cement factories are given below. Cement No. 1 is a Holstein brand; Nos. 2, 3 and 6, Silesia, and Nos. 4 and 5, puzzuolana cement. While the last-mentioned cannot properly be compared with Portland cement, they are inserted here, to show the marked difference of the behavior of the two varieties. All these cements fulfill the Prussian regulations. They have a tensile strength, after 28 days, when used in 1:3 mortar, of more than 16 kg. per square centimeter (230 lbs. per square inch) and a compressive strength of more than 160 kg. per square centimeter (2 300 lbs. per square inch). The sieve of 900 meshes rejects less than 10%, and they are of constant volume. The table shows the quantities lost by wear of these six brands, in cubic centimeters, for specimens which hardened in damp rooms in the air, and also for specimens which were kept in air for 24 hours, and the remainder of the time under water, being taken out of the water one hour before abrasion.

For all these cements the loss of weight of the air specimens is greater than that of the water specimens. The loss of weight of the seven-day specimens is only slightly greater, indeed less in some cases, than for the 28-day specimens. This striking phenomenon is explained by the circumstance that after hardening for seven days the specimen has a certain toughness, it being in the first stage of

development; after 28 days, however, it has acquired a slight brittleness, which renders it more susceptible to abrasion and this it

TABLE SHOWING LOSS OF WEIGHT OF CEMENTS BY ABRASION.

Number.	Length of tests.	Hardened in Air.					Hardened under Water.				
		Neat cement.	1 cement. 1 sand.	1 cement. 2 sand.	1 cement. 3 sand.	1 cement. 4 sand.	Neat cement.	1 cement. 1 sand.	1 cement. 2 sand.	1 cement. 3 sand.	1 cement. 4 sand.
1.....	7 days..........	5.5	4.2	3.5	6.1	8.9	5.0	3.7	3.8	7.9	10.4
	28 days..........	7.9	4.5	1.9	9.7	13.8	2.9	1.8	2.7	4.1	6.8
2.....	7 days..........	4.6	2.5	3.4	8.3	9.5	4.6	1.7	3.0	6.5	8.8
	28 days..........	3.9	2.0	3.5	6.0	7.3	3.6	1.8	2.3	5.0	5.6
3.....	7 days..........	5.4	2.9	6.1	18.3	62.8	2.4	2.1	2.1	4.7	15.9
	28 days..........	2.4	1.6	1.9	2.3	22.9	2.2	1.3	1.4	1.8	2.2
4.....	7 days..........	10.4	3.9	3.9	7.3	17.3	4.0	2.6	2.5	3.6	4.6
	28 days..........	9.0	4.2	3.4	5.2	14.9	3.6	2.8	2.1	2.1	1.8
5.....	7 days..........	10.6	7.6	10.2	19.2	28.7	7.0	5.9	7.1	15.7	17.4
	28 days..........	5.3	1.6	1.6	9.0	11.6	5.8	0.9	1.1	2.3	13.4
6.....	7 days..........	6.2	2.3	4.2	6.5	17.1	3.5	1.3	2.2	5.0	10.9
	28 days..........	5.3	2.2	3.3	4.4	8.9	3.9	1.3	2.2	2.7	3.9

practically always retains. The air specimens also possess a greater brittleness than the water specimens. For both kinds the table shows that the loss of weight of the neat cements is greater than that of mortars until the dose of sand becomes very high. Hence, the higher the proportion of sand can be made, until the loss of weight of a mortar exceeds that of a neat cement, the better will it be for floors and pavements, as far as wearing qualities are concerned.

By the grinding action of the apparatus small particles are torn off the specimen. These particles are fine flour of cement for neat cement specimens; for a specimen having 1 part sand to 1 of cement this fine flour cannot be formed from the cement between the grains of sand as long as there is sufficient binding force to hold the grains together to resist the tangential action of the grinding plate. This binding force of the cement must, of course, be less the less the proportion of neat cement in the specimen and the greater the dose of sand. One cement will possess more, another less, of this binding force, and can hence bear a greater or less proportion of sand with an equal loss of weight. Furthermore, it will be readily seen that the binding strength of a cement is increased by the power of the cement grains to adjust themselves close to the quartz grains; in other words,

by the fineness of the cement. In fact, we see from the table that the very fine cements, to which class belong the puzzuolanas, possess the greatest cohesive strength, entirely independent of their remaining properties. This may be more plainly seen if we select the 28 days' wearing tests and show them for air and water mortar in a graphic manner. The doubly hatched areas in Fig. 15 show the mortars which hardened under water.

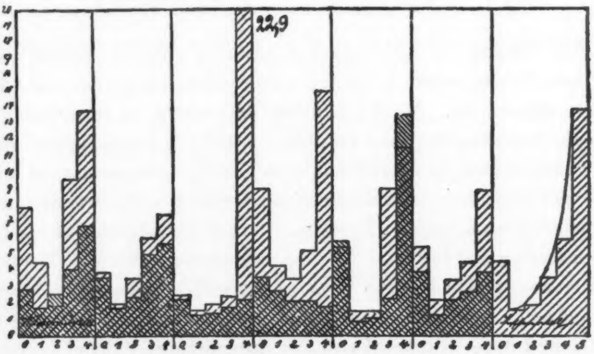


FIG. 15.

The abscissas are arbitrarily assumed and the co-ordinates show the wear in cubic centimeters of various Prussian regulation cements mixed in the proportions of 0, 1, 2, 3 and 4. A great similarity is shown by the figure in the wearing qualities of the water specimens in cements Nos. 1, 2 and 6. The decrease in binding strength is very nearly proportionate to the amount of sand added. No. 3 shows (on account of its extraordinary fineness) a strikingly low amount of wear which continues for hydraulic mortar up to an addition of from 3 to 4 parts of sand, while air mortar loses its bond in a marked degree with 4 parts of sand. The two puzzuolanas show a wide variation in the amount of wear, which amount, although especially in the case of the hydraulic mortars, is not great, nevertheless makes them compare unfavorably with the Portland cements. For the sake of comparison a representation of the relative wearing qualities has been added to the figure. This is the mean of tests made by Professor Böhme on samples furnished by 28 different factories. The figure shows plainly in what manner the wear increases with the increased amount of sand.

The least loss by wear is found in 1 part cement to 1 part sand. In the mean the amount lost by wear is:

For neat Portland cement				4.7	cu. cm.
" 1 cement, 1 sand				1.7	"
" 1	"	2	"	1.9	"
" 1	"	3	"	3.6	"
" 1	"	4	"	5.9	"
" 1	"	5	"	13.8	"

For comparison other abrasion tests are given as follows: plaster of paris, Rabitz patent, 5.5 cu. cm.; slag plates, 2.8 cu. cm.; sandstone, 1.7 to 15.0 cu. cm. Much additional data might be furnished showing the importance of tests for abrasion, but the limited space forbids.

In conclusion, two desirable tests remain to be mentioned which have not come into general use because reliable and convenient apparatus has been wanting. These are the test for adhesion of the binding materials and the tests for imperviousness to water. The Berlin conference of 1890 left the question regarding the adhesive strength of hydraulic binding materials unsettled, but it is to be hoped that the near future will, thanks to the unremitting labors of individual members of the Commission, bring a satisfactory solution. The history of the Association of German Portland Cement Manufacturers is a guarantee that it will not cease pushing its scientific investigations regarding the properties of its product, thus conferring blessings upon the German Portland cement industry and benefits upon architects and engineers over the entire earth.

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634.

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ON THE MANUFACTURE AND TESTING OF PORTLAND CEMENT.

By HENRY FAIJA, M. Inst. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Portland cement, as is well known, consists of a chemical combination of lime, silica, and alumina with iron in certain well-defined proportions, together with alkalies, magnesia, etc., which enter, in a minor and less essential degree, into its composition.

The lime may vary from	58 to 64%
The silica " "	18 " 24 "
The alumina and iron from	8 " 14 "

the three together amounting to about 95 or 96% of the whole, and the properties of the cement produced will depend, in the first instance, on the proportions which these ingredients bear to one another. The magnesia, alkalies and sulphuric anhydride, which are found in

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

small varying quantities in nearly every cement, affect its properties in a minor degree, in accordance with the proportions which they bear to each other, and to the whole.

The difference between a hydraulic lime and a Portland cement is that in its composition hydraulic lime contains a larger percentage of lime than a Portland cement, and consequently its nature is such that it requires hydrating before use, whether that hydration be effected by grinding or slacking it with water, whereas Portland cement is fit for use without previous hydration ; this difference being due not only to the difference in composition, but also to the degree to which calcination is carried.

Hydraulic lime is the product of the simple calcination of a limestone rock, and any slight variations in the composition of the natural rock does not materially affect the resulting lime ; but the composition of a Portland cement has to be kept within certain well-defined and comparatively close limits, and consequently a natural rock is seldom found which is capable by simple calcination of producing a Portland cement, and it is therefore necessary to find such limestones and clays or shales, which, by their admixture in the proper proportions, will produce a material having the desired composition.

The processes of manufacturing Portland cement, therefore, consist in the first instance of obtaining a perfect mechanical admixture of such raw materials as are suitable and available, and subsequently reducing this mechanical admixture to a chemical one by calcination, and afterwards grinding the clinker so produced.

Given any materials which contain among them the lime, silica and alumina, and which may, by proper admixture in definite proportions, produce the components of a Portland cement, then Portland cement may be produced from them; but it is needless to say that the commercial aspect of the undertaking should be considered, and in many cases it is evident that the cost of production would be prohibitive. It is therefore necessary, in selecting the raw materials, to select those which are the most amenable to reduction and admixture.

Those materials which are capable of reduction by water are not only the most economical to reduce, but are also capable of producing the most perfect mechanical admixture, and it is needless to say that the more perfect the mechanical admixture of the several ingredients, the more perfect is the chemical compound produced by calcination.

The chalks and clays from which Portland cement is produced on the Thames and Medway, in England, and the chalk and clay which are used at Yankton, Dakota, U. S. A., at the works of the Western Portland Cement Company, which the author designed for the proprietors some four years ago, are examples of materials which lend themselves easily to disintegration and reduction by water.

Other raw materials which are not capable of reduction by water have to be ground to powder and then mixed, and it is evident that such a process must be more expensive than the former; still, by the adoption of reducing machinery, suitable to the materials to be treated, the extra expense need not be great. Examples of such materials are to be found in the blue lias formation from which many cement works in the Midland Counties of England derive their supply of raw material. In this case, the stone, and the shale which separates the beds of stone, are both used in the production of cement, the proportion of shale to stone used being determinen by the chemical composition of each; but as both are capable of being ground as brought from the quarry, they are generally ground in their proper proportions together, the grinding and subsequent pugging effecting the mixing.

Another modification in the means of obtaining a mechanical admixture of two materials, is where one is capable of being reduced by water and the other is not; as, for instance, a hard limestone and a clay. Such an instance, among many others, is found at Parahyba do Norte, Brazil, at works which the author designed three years ago. In this case a hard limestone is used in conjunction with a river mud, and the author found that the best means of producing a thorough admixture of the materials, was by grinding the limestone, drying and then grinding the mud, and then weighing and mixing them in their proper proportions.

It would be quite impossible to enumerate the several mechanical devices which have to be used for the economical production of a perfect mechanical admixture of the different materials. It is necessary to consider the physical properties of the materials to be dealt with, and to treat them in such manner as experience may suggest to be the most satisfactory, combined with due economy.

Having so far considered the method of preliminary dealing with the raw materials, the next process is to make them into such form that they are capable of being loaded into a kiln for calcination.

For the further treatment of materials which are reduced and mixed by water, there are two well-known processes, both processes being subject to many variations in detail. The first, and the oldest, and probably, all things considered, the most satisfactory, except in the matter of economy, is to wash the chalk and clay together in a wash-mill with a very large quantity of water. The slip so produced runs away by an overflow, and is conducted by proper channels into large reservoirs or backs, where the solid particles in the slip gradually sink to the bottom, and the clear water is drawn off by weirs and sluices. When a back or reservoir is full, and the slip has attained sufficient solidity to be removed in barrows, it is laid on the drying floor, and subsequently loaded into the kiln. This process, it will be readily understood, produces the most perfect mechanical admixture of the two materials which it is possible to attain.

The second well-known method is to wash the chalk and clay in a wash-mill as before, but with considerably less water, and instead of taking the overflow, the slip produced is simply allowed to pass through a grating, and, consequently, it is not reduced in the wash-mill to that same degree of fineness to which it is in the previously-described process. In order, therefore, to obtain that required fineness, the slip, as it passes through the grids of the wash-mill, is conducted to a pair of ordinary millstones and ground, from whence it passes direct on to the drying floors, and is dried ready for calcination.

As will be seen, these two processes lend themselves to many modifications, in accordance with exigencies of the site, etc., and the fancy or whim of the manufacturer.

When dealing with materials which are reduced by grinding, there are two well-known methods. The one is to mix it in a pug mill with a fairly large quantity of water, reducing it into a kind of stiff slip, which may be dried on a drying floor; the other is to mix it with a small quantity of water and make it into bricks in any of the well-known dry brick machines, which bricks are then dried in the ordinary way previous to calcination.

The difference in the two processes does not seem very great, but there is perhaps more difference between them than is apparent at first sight. When mixed into a stiff slip, there is possibly from 25 to 30% of water to evaporate from it before it is sufficiently dry to load into the kiln, at the same time the dried slip has the advantage of being more

or less porous, and consequently is fairly easy to calcine. In the process of compressing the slip into dry bricks, or briquettes, the amount of water to evaporate is perhaps only 12 or 13%, but owing to the density of the brick it is difficult to evaporate this water, and the dried brick does not lend itself readily to easy and regular calcination in the kiln.

The means adopted for drying the slip, slurry, or bricks, are various. The oldest and perhaps best known is that of having ordinary tiled floors with flues underneath, through which the combustion from coking ovens is passed, the slip being laid on the top of the tiles; by this means the the slip is dried, and a certain quantity of coke is produced, which is used as a supplementary supply to that which is required for the calcination of the cement in the kilns. Other floors are of iron plates, under which free steam is passed, and again there are many drying floors which are constructed like ordinary brick-drying floors, without any pretention to economy. But the most advanced method is to construct the drying floor at the level of the top of the kiln, and to use the waste heat from the kiln for drying the slurry or bricks for the next loading. Kilns or drying floors on this principle have been the subject of innumerable patents, both in the United States and Great Britain, and it would be impossible to even enumerate them, to say nothing of considering their respective merits. It is only possible to say, that the primary object of a kiln is to calcine the cement evenly and regularly, and that the drying of the slip by the waste heat from it must be subservient to the proper calcination of the cement.

So far, the preliminary treatment of the raw materials, their proper and thorough admixture, and their manufacture into a suitable form fit for calcination, have only been considered, and it is needless to say, that no matter how perfectly the manufacture has been so far carried, the final result will not be satisfactory unless the calcination is perfect. The requirements of calcination are: that the calcination should be stopped just short of vitrifaction; that the proper degree of calcination should be effected rapidly, and that the clinker should be burned, not baked; that the product of a kiln should show an even and regular degree of calcination throughout; and lastly, that these results should be obtained with due economy with respect to fuel; and the kiln which best satisfies these requirements is the one to be adopted.

At the same time it must not be forgotten that although the ingredients of a Portland cement are the same, no matter where, or from what raw materials the cement is made, and that the chemical combination of those ingredients should be carried to the same degree of firmness, still different materials require different degrees of calcination, and that a kiln which is eminently suited for one slip is not of necessity suitable for the calcination of a slip produced from other raw materials. The whole duty of a kiln is first to expel the carbonic acid, and what remains of moisture, from the slip, and then to create an intimate chemical combination of the ingredients.

On drawing a kiln, all light burnt portions should be picked out, and only the thoroughly burnt clinker passed to the crushers for subsequent grinding; and it is usual to put the light burnt on top of another kiln for further calcination, or in some works small subsidiary kilns are used for its further calcination.

The calcination of a Portland cement has hitherto been carried out in intermittent kilns, *i, e.*, a kiln is loaded, fired, allowed to cool, and drawn, and hence a great loss of heat and considerable wear and tear caused on the kiln, through alternate expansion and contraction; but the difficulty of altering this and adopting a continuous or running kiln has been the difficulty of obtaining a sufficiently refractory material to form the lining of the kiln; not so much on account of the heat in a cement kiln being greater than that to which fire bricks are subjected in many other manufactures, but to the presence of the lime in the cement acting on the silica and alumina in the bricks, causing them to flux and enter into combination with the slip of the cement.

The economical grinding of cement has lately attracted the attention of a great number of inventors, and mills or grinding machines of almost every conceivable design and principle have been patented; but whether any of these will survive and eventually supersede millstones is a very problematical matter. The two principles which have perhaps attracted the greatest attention are those of edge-runners and ball mills, and the economy in power by both these principles over ordinary millstones is very considerable, and the cost of repairs and maintenance is also, in most cases, considerably reduced; but whether the grinding is as efficient is another question altogether. Mere fineness does not satisfy the question, as a cement may be ground to an equal fineness in two different mills, and yet one will be all grit and

the other all flour; and the more floury nature a cement is, the better will be the results obtained with it, both in the testing-room and in actual practice; and undoubtedly no grinding machine that has as yet been invented will produce the same percentage of flour on equal grinding as the ordinary millstone. Mills on the ball principle give better results than those on the edge-runner principle, but are not so efficient as millstones.

The power consumed by the several principles, reduced to the production of 1 ton of cement per hour, may be approximately stated to be as follows :

For millstones.............	30 to 32 I. H. P.	per ton per hour
Ball principle..............	16 to 18 I. H. P.	" "
Edge-runner principle......	12 to 14 I. H. P.	" "

in each case the cement being ground to a fineness of about 5% residue on a 50×50 sieve, and it will thus be seen that the power required is proportionate to the amount of flour produced.

The great objection to millstones, from a manufacturer's point of view, is the great expense entailed in dressing them, as in a hurst of four pairs of stones, one pair will always have to be up being dressed; and there is, therefore, not only the expense of dressing, but there is the increased capital charge in requiring four mills to do the work of three. It seems possible, though the author has not had the opportunity of trying it, that by giving the millstones a fine dress with a considerable depth of face, the first grinding of the cement might be effected in one or other of the grinding machines and finished only in the millstones.

Before leaving the subject of the manufacture of cement, the author would like to point out to manufacturers, or intending manufacturers, the necessity and great advantages of having ample warehouse room for the finished cement. Very few cements are fit for use immediately they are ground, and all cements are improved by judicious and careful warehousing. Not only therefore is a manufacture improved by having ample warehouse room, but ample warehouse room enables the manufacturer to continue manufacturing his full output, even when his sales may for the moment be a little slack.

The object of testing cement is to obtain a knowledge of the material which is about to be used; and the author maintains that that

knowledge can best be obtained by gauging a cement by itself with the addition only of water, and without the addition of sand or other materials, as these themselves, by variations in their composition, form and nature, introduce an element of error, independently of any good or bad qualities in the cement; also, that the results obtained in the testing-room and laboratory are infinitely superior, so far as strength is concerned, to any that can be obtained in actual practice; and that it is the object of the manipulator in the testing-room, to obtain the very best results which his knowledge and skill make possible.

A very true knowledge of the value of a cement may be obtained by determining the following properties:

1. The time which a cement takes to set.
2. Its soundness or freedom from blowing.
3. The fineness to which it is ground.
4. Its tensile strength at three or seven days.

Of these the most important is, of course, its soundness, for if a cement will, after a longer or a shorter period, "blow" and destroy the work of which it forms a component, it evidently does not matter how long it takes to set, to what fineness it is ground, or what tensile strength it develops within the limits of time of an ordinary test.

The manner of carrying out this test will be considered later on.

The setting properties of a cement may be determined by taking a few ounces of the cement and mixing it with the very smallest quantity of water which will allow of its being worked up with a trowel into a tenacious mass, which will retain the form into which it is made. This should be shaped up into a pat of about 3 ins. long, by $1\frac{1}{2}$ ins. wide, and $\frac{3}{4}$ in. thick, and placed on a non-porous slab; and it may be considered "set hard" when the pressure of the thumb nail will no longer mark it. Or if the thumb-nail test is considered too primitive, a Vicat needle may be used; the needle having a flat point with a diameter of 0.1 in., and loaded with a weight of 3 lbs. The needle should be allowed to remain on the pat for about one minute, and when on removal no mark is left, the cement may be considered set hard. There is, however, an intermediate stage which should be noted, viz., the time of "initial set," and this is of more importance than the time which a cement takes to finally set. A cement when it is first worked up into a pat, has a glossy, wet appearance,

which is due to the excess of water which was used in gauging remaining on the surface, and it will remain in this condition until the setting commences; the water will then leave the surface, and become absorbed by the cement as it sets or crystallizes, and when once this process has commenced, any disturbance of the cement will destroy its constructive value ; hence it will be seen that the time of "initial set" of a cement, or the time that elapses between the first addition of water and the commencement of setting, defines the time which may be taken for the proper manipulation of the cement in the work in which it is to be used. The time which it takes for a cement to set hard is not of such importance, and also cannot be determined with the same accuracy. The initial set is the commencement of an actual chemical process which continues until the cement has attained its ultimate hardness and strength, while the time of "set hard" forms only a somewhat more or less accurately to be determined period. At the same time the comparisons between the time of "initial set" and "set hard" afford many opportunities of obtaining considerable knowledge of the nature of a cement, and the manner in which it may best be used.

Cements may be divided into two classes—quick setting and slow setting. A quick setting cement may have an "initial set" of seven or eight minutes, and will be "set hard" within the hour ; in a slow setting cement the time of initial set is sometimes very difficult to define, but it may be set hard in from two to six hours.

The comparative constructive values of quick or slow setting cements must depend entirely on the work for which the cement is to be used. It cannot be said that a quick setting cement is better than a slow setting cement, or a slow setting cement better than a quick setting cement ; they may be equally good cements, though not adapted to the same purpose. There are, of course, some cements which do not arrive at the point which may be considered "set hard" in less than 24 hours; there are also some of the quick setting cements which become set hard almost immediately on the addition of water, rendering it absolutely impossible to gauge them. Either of these extremes are undesirable, and a cement that is abnormally quick setting or abnormally slow setting, should not be used in any work until after very careful tests and examinations have been made to otherwise determine their quality. There are some cements which have a very quick

"initial set," but after that take some considerable time to harden; others again, though really quick setting cements, approach to the characteristics of slow setting ones by having no "initial set" which can be readily defined; all these may be perfectly good cements, but as they possess abnormal characteristics, should be very carefully examined before use.

The causes which affect the setting of a cement are: primarily, the proportions to each other of the materials of which it is composed; and secondly, the degree of their chemical affinity, or in other words, the degree or manner of calcination to which they have been subjected.

In former days a very slow setting cement was supposed to be so, because it contained a very large percentage of lime. This is true only so far that a cement containing a large percentage of lime will probably be slow setting, but the slow setting nature of a cement may be due to many other causes, and the most marked of these is the degree of calcination to which it has been subjected. Given any combination of lime, silica and alumina, which falls within the limits of an ordinary Portland cement compound, the degree to which it is calcined will make it, within limits, dependent on its composition, either a quick or a slow setting cement. The percentage of alumina and iron again will affect the setting of a cement to a great extent.

Independently, however, of the chemical composition and calcination of a cement, there are other matters, of a purely mechanical nature, which affect the setting powers of a cement. The age of a cement is perhaps the most important, and there are one or two peculiarities in this; a cement when first ground may generally be gauged very easily with a comparatively small quantity of water, but when that cement has been in the warehouse for 24 hours it may be almost impossible to gauge it, as it sets or commences to set almost directly the water is added; after this period, however, the cement gradually becomes slower setting, and even a very quick setting cement will in a few months become quite slow enough for all ordinary purposes, provided, of course, that during that period it has been kept in a dry and cool warehouse, and has not been affected by damp or wet, or otherwise damaged.

The tensile strength of a cement is the test which is generally considered to most accurately define its value for constructive purposes;

needless to say the strength of a cement will be dependent on its composition and calcination in a similar manner to the peculiarities of setting which have already been referred to. A quick setting cement naturally attains greater strength in a shorter period than a slower setting one, but a slow setting cement has probably the greater ultimate strength.

The manner of carrying out this test is to gauge briquettes in gun-metal moulds, having a sectional area at the smallest part of 1 sq. in.; the briquettes after being left in the moulds for 24 hours in order to become perfectly set, are removed and placed in tanks of water, in which they are allowed to remain until they are to be tested. The usual and most convenient periods to test the briquettes for tensile strength, is at the expiration of three and seven days from the time of gauging. It is usual to make five briquettes to test at each date, and the average strength of the five taken as representing the tensile strength of the cement at those periods. It is also perhaps desirable to occasionally make briquettes to test at a longer date, usually 28 days, as by that means a corroboration of the opinion formed of the cement at the expiration of the seven days' test may be obtained. It may not perhaps be apparent that it is absolutely necessary to make tests at two or more dates in order that the value of the cement may be arrived at, but it will be readily seen that the increase in strength between the several dates of testing gives an indication of its growth, and hence an approximation of its ultimate strength may be arrived at.

It is difficult to define any hard and fast rule which should govern the increase in the strength of a cement between the three and seven days' test. Many quick setting cements will carry a tensile strain of 400 lbs. on the inch section at the expiration of three days from gauging, and will probably carry 500 lbs. at the expiration of seven days; this would show an increase of 25%, and is perhaps as much as can be expected from a cement which develops a very high tensile strength at the early date. A slow setting cement will probably at the three days' test not carry more than 300 lbs. on the square inch, and perhaps 450 lbs. at the expiration of seven days from gauging, which would represent an increase in tensile strength of about 50 per cent. It is also known from experience that most slow setting cements will continue to increase in strength for a much longer period than the

quicker setting ones, and consequently the slower setting cements, under ordinary circumstances, will attain a greater ultimate strength.

It will therefore be seen that if a slow setting cement is required, it is not advisable to demand, in a specification, too high a tensile strain at the early dates, and possibly 350 lbs. on the square inch at the seven days' test is sufficient, whereas if a quick setting cement is required, 400 lbs. is nothing too much to demand. Of course there are variations from this regular order of things, and sometimes a slow setting cement may be found that carries 400 lbs. or 500 lbs. at the expiration of the three days' test, also there are quick setting cements that have a comparative low tensile strength at the early dates, but give indications of considerable growing powers; and it is only possible to say that any cements that develop abnormal strength, whether in excess or deficiency, should be looked upon with a certain amount of suspicion until their properties and qualities are fully ascertained.

Latterly, the author has had several specifications before him, which, in addition to naming the minimum strength at each date, have also defined the maximum. This, no doubt, has been devised with the object of securing a certain good increase in strength between the several dates at which the cement is tested, but it seems almost needless to point out that such a specification defeats its own object, for whereas the best results of a cement can only be obtained by careful and proper manipulation in the testing-room, a lower result may be easily secured by indifferent or careless gauging.

The sand test consists in gauging the cement with 3 parts of sand, which should be of approved quality, sifted to a certain size and properly washed and cleansed, but the difficulties of carrying out the test are many. Variations in the form and hardness of the grain of sand materially affect the result of the test, and the difficulties of manipulation and of making solid briquettes render it altogether an undesirable test to adopt, irrespective of which the test is a long one, the briquettes not being tested until 28 days after gauging, and it is needless to say that in very many cases it would be impossible to wait that length of time to know the value of the material which it is required to use. In the author's opinion cement should be tested by itself, not only because the manipulation is considerably simpler, but because it is unwise to introduce into a test extraneous matters and complications which are in themselves open to considerable variation.

If it is desired to ascertain the strength of a mortar compounded with any particular cement, then let the cement be gauged with those aggregates and sand which are to be used on the work ; by this means some definite information may be obtained as to the strength and binding power of the mortar which is to be used ; but to test a cement with what it is pleased to call a normal or standard sand, gives practically no information in this direction, and simply tends to complicate and confuse an otherwise simple test.

The fineness to which a cement is ground materially affects its constructive value, but it is unnecessary to say much about it, as the principle of fine grinding is perfectly well understood. Probably, if a cement was ground to an impalpable powder, the best results would be obtained; but, as it is impossible for the manufacturer to produce this degree of fineness with the machinery at his command, except at great cost, it is not desirable to demand such extremely fine grinding. A cement that will all pass through a sieve having 625 holes (25^2) to the square inch, and which will leave a residue of from 5 to 8% when sifted through a sieve having 2,500 holes (50^2) to the square inch, is for all practical constructional purposes ground fine enough.

It is now necessary to refer to the property which it is essential that all cements should possess, viz., absolute freedom from all indications of either expansion or contraction, and that when once set it shall in no way alter its form, crack, or disintegrate.

One of the peculiarities of Portland cement is, that if its components are improperly proportioned, or its manufacture has not been properly carried out, it may have a tendency, after being gauged and mixed with water, to crack, expand, or disintegrate and fall into powder. This peculiarity is known under the cognomen of "blowing," and when a cement is said to "blow" or to be a "blowey cement," it means that after the cement has been used it expands, cracks or disintegrates, destroying the work in which it has been used.

The cracks, however, which are seen in concrete work are not always due to the use of a "blowey cement," but may be due to constructional causes, or to the expansion and contraction of the structure due to variations in temperature, or to the natural contraction of the mass ; and a simple crack in a piece of concrete would hardly be indicative of a "blowey cement" unless accompanied by other indications, such as friability or absolute disintegration.

Concrete or mortar, again, may disintegrate, crack and fall to pieces from other causes than the use of a "blowey cement." There are certain matters often present in aggregates which, by not allowing the cement to set properly, are antagonistic to the production of a sound concrete or mortar; the principal of these are dirt and loam, and there is no doubt that in numerous instances the cement has been blamed when the real fault has been either that the aggregate with which it was used was dirty or unsuitable, or that the concrete or mortar had been improperly manipulated ; and a user of cement should be as careful in his choice of aggregate, sand and water as he is in his choice of cement. The best aggregates are those which, while having ample strength, are somewhat irregular in form, and slightly porous, and which have been carefully and thoroughly washed before being used. The scope of this paper, however, does not extend to the choice of aggregates and manufacture of concrete, but as these, if improperly selected and manipulated, may cause a failure, irrespective of the quality of the cement, it seemed necessary to allude to the subject.

Returning, however, to the subject, a cement may blow within a few hours of its being gauged, or it may not blow until several months afterwards. A cement may blow when it is very fresh and newly ground, and will lose that tendency after it has become aged. Some cements will blow whether they are new or old.

The cause of "blowing" in a cement is generally due to an excess of lime in its composition, or to an imperfect combination of the lime with the silica and alumina. It may, however, be due to other causes; as, for instance, to the presence of other basic materials unduly entering into the composition of the cement by the use of improper raw materials. One of these, magnesia, created a considerable scare a few years ago. Sulphate of lime or gypsum is another, which, although it has not attracted the attention of users like magnesia, is more often found in cements, and, when in any considerable quantity, undoubtedly has a very great power of rendering a cement blowey. As previously stated, it is hardly fair to the user that he should be required to make himself *au fait* on the several causes which constitute a blowey cement ; it should be enough for him to determine, and be able to ascertain, whether or not a cement is blowey, and leave it to the manufacturer to properly compound the cement, and correct his manufacture.

Several means have from time to time been devised for ascertaining within the limits of time of an ordinary test whether or not a cement is absolutely sound, and that process or test which was devised by the author some 14 years ago is now in general use. The apparatus in which the test is carried out, and the means of carrying out the test, are fully described in the *Transactions* of the American Society of Civil Engineers, Volume xvii, November, 1887, in a paper which the author had the honor of communicating to that Society, headed "Portland Cement Testing." Briefly, it is a vessel containing water, the water being maintained at an even temperature of about 110 to 115° Fahr.; there is a cover to the vessel, so that above the water there is a moist atmosphere which has a temperature of about 100° Fahr.

The manner of carrying out the test is by making a pat, in the manner already described, on a small piece of glass; immediately the pat is gauged it is placed on a rack in the upper part of the vessel and is there acted upon by the warm vapour rising from the hot water, when the pat is set quite hard it is taken off the rack and put bodily into the water, which, as has already been stated, is maintained at a temperature of 110 to 115° Fahr., and in the course of 24 hours it is taken out and examined, and if found then to be quite hard and firmly attached to the glass, the cement may at once be pronounced sound and perfectly safe to use; if, however, the pat has come off the glass and shows cracks or friability on the edges, or is much curved on the under side, it may at once be decided that the cement in its present condition is not fit for use. The blowing, however, may only be due to the extreme freshness of the sample, and though a cement in its fresh condition is unfit to use, it may be a perfectly good cement when aged, and in order that a cement should not be condemned unjustly it is advisable, in the event of a cement showing a tendency to blow on the first experiment, to lay some of it out in a very thin layer on a tray, so that it may be thoroughly cooled, and in the course of a few days another pat should be made and treated in a similar manner; if this pat goes through the ordeal successfully and is perfectly sound, it may be fairly assumed that the cement only requires ageing to be a perfectly useful one; if, on the other hand, the second test proves unsatisfactory, it would not be advisable to use the cement. A cement may show indications of blowing while it is on the rack in the moist heat of the vessel; if this happens it is needless to say that no corroborative test is required, the cement must be absolutely worthless.

The ordinary practice of carrying out this test is to make the pats in the morning, at, say, 10 or 11 o'clock, and to place them in the upper part of the vessel, and before leaving in the afternoon, say, at 5 o'clock, to put them in the water underneath, and to examine them for soundness the next morning, so that in 24 hours after the receipt of a sample its soundness may be known; and the author feels sure that both users and manufacturers will agree with him in the importance and value of the test.

It is hardly possible to dismiss the subject of the soundness of cement without reverting to a test that was suggested some three years ago by M. Deval, and which was reported upon by M. de Chatelaine, and known as the "hot test." It consisted in gauging briquettes in the ordinary way, either neat or with sand, and when they were set, placing them in water which was kept at a temperature of 80° Cent. (*i.e.*, about 177° Fahr.), and it was maintained that, by so treating a briquette, the strength due to 28 days, as carried out in the ordinary way, was attained by this method in considerably less time, and thereby the constructive value of a cement could be more quickly ascertained. It was also maintained that this treatment of a cement determined whether it was a sound cement or not, for if the briquettes did not stand this excessive temperature, but cracked or became soft, then it was asserted that the cement was an unsound one.

When the author devised his apparatus for determining the soundness of a cement, which has already been described, he naturally had to make a great number of experiments before deciding on a temperature which it was advisable to adopt, and he then found that although some cements would bear being almost boiled, many cements that were in every respect good and sound cements would not stand the moist atmosphere and subsequent warm bath if the temperature was higher than that which he adopts, viz., 116° Fahr. for the bath; he, therefore, when M. Deval's test was made public, made a long series of experiments to satisfy himself that he had made no false deduction in his previous experiments. The conclusion which he arrived at after these experiments with the "hot test" were the following:

1. That if a cement was really blowey, his own apparatus showed it equally with the hot test.
2. That the induration of a good cement was hastened as much, and sometimes more, by immersing the briquettes in water

maintained at the comparatively low temperature of 116° Fahr., as when immersed in a bath at the enormous temperature of 177° Fahr.

3. That no "fully" limed, as distinguished from "over" limed, cements would withstand the "hot test," but that all fully or over-clayed cements would stand it, and that consequently the test acted prejudiciously to what is accepted as a good cement, and gave preference to the over-clayed and quick-setting ones.
4. That nearly any cement that had been aged sufficiently would stand the hot test.

As the result of these experiments the author came to the conclusion that the hot test could hardly be considered a satisfactory test; and as the test has not made any great headway with either users or manufacturers, it seems that the conclusion he arrived at was fully justified.

In conclusion the author begs to submit the following notes on sampling and cement testing for the consideration of cement users. The specification is one which he has now adopted for several years, and finds that it in every way satisfies the requirements and ensures the delivery of a good cement.

Sampling.—When it is required to take a sample of cement for testing, it is desirable, in order to secure a fair average sample, to take a small quantity from several out of every 100 barrels or sacks, or the equivalent in bulk, and mix them all well together before taking the quanity required for testing, the samples being taken well from the center of the sacks, barrels, or bulk, and not from the surface, as that portion may have been accidentally damaged. When sampling from fresh or new cement, it is always advisable to cool it by laying it out in a thin layer for a few days, before putting the test in hand.

Gauging and Manipulation.—To obtain the best results, the minimum of water should in all cases be used when gauging cement. Small experimental pats should be made with a weighed quantity of cement and a measured quantity of water, in order to determine the exact amount of water required to properly gauge the particular sample under consideration. Having arrived at this knowledge, a sufficient quantity of cement for filling a nest of moulds should be weighed out, and the proper amount of water added thereto. It should

then be gauged with a trowel to the proper consistency, and filled into the moulds, being lightly rammed and gently shaken in order to remove all air bubbles. The briquettes should then be smoothed off and placed on one side. The whole operation from the time of adding the water to the cement to placing the briquettes on one side should not exceed five or six minutes. The briquettes should be removed from the moulds at the expiration of 24 hours from gauging, and placed in water, where they should remain until due for testing. It is customary to determine the tensile strength at the different dates by the average of five briquettes at each date.

Three pats should be made on pieces of glass or other non-porous substance, and their behaviour watched under the following conditions: Pat No. 1 may be left in the air, and No. 2 should be put in water as soon as it is set hard. Pat No. 3 should be treated in the apparatus for determining the soundness of cement.

Specification.

No. 1. *Fineness.*—To be such that the cement will pass through a sieve having 625 holes (25^2) to the square inch, and leave only 8% residue when sifted through a sieve having 2 500 holes (50^2) to the square inch.

No. 2. *Expansion or Contraction.*—That a pat made and submitted to moist heat and warm water at the temperatures and in the apparatus already described shall show no signs of expansion or contraction (blowing) in 24 hours.

No. 3. *Tensile Strength.*—Briquettes which have been gauged, treated and tested in the prescribed manner, to carry an average tensile strain, without fracture, of at least 250 lbs. per square inch at the expiration of three days from gauging; and those tested at the expiration of seven days from gauging to show an increase of at least* per cent. over the

* If a 28 days' test is required, the average tensile strength should be at least 450 lbs. per square inch, and it must be noted that the increase in strength developed between the different dates is an indication of the growing strength of the cement, and admits of an approximation being formed of its ultimate strength; but it is impossible to lay down any hard and fast rule as to what the increase between the different dates should be; a slow setting cement will probably increase 50% between the three and seven days' test, and 25% between the seven and 28 days; whereas, a quick-setting cement may increase but very little. All cements should, however, show an appreciable increase in strength between the different dates; but as the increase in strength is not so great with quick-setting cements as with slow-setting ones, the tensile strength of a quick-setting cement should be greater at the shorter dates than a slow-setting one. All cements, more especially quick-setting ones, become slower setting and generally improve in tensile strength with age.

strength of those at three days, but to carry an average tensile strain of at least 350 lbs. per square inch.

The strain should be applied to the briquette at the rate of 400 lbs. per minute.

It is needless to say that it would be possible, without much difficulty, to continue the enumeration of the properties of cements and to discuss their peculiarities for a considerable length of time, but the author thinks he has already mentioned the most important, and is anxious not to encroach too far on the time of the Congress. He would, however, like to add that he fully appreciates the high honor which it has been his privilege to receive at the hands of the Board of Direction of the American Society of Civil Engineers and trusts that the somewhat discursive essay which he has presented may lead to such a discussion as will advance the knowledge of the manufacture and the use of Portland cement.

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TOPOGRAPHIC SURVEYS.

By HERBERT G. OGDEN, Assistant U. S. Coast and Geodetic Survey.

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The geography of the surface of the earth, defining the boundaries of the land, the extent of the oceans and seas, and the discovery of the sources of rivers, has always excited an interest in the more intelligent of mankind. It is but natural that beings endowed with the attributes of man should seek for knowledge of their environments, and that, as the master-minds become more highly cultivated, this knowledge will be sought with greater intensity. Volumes have been written on the earlier theories of the earth's surface, and there are libraries of works on the explorations and discoveries that have been made. They evidence the progress of geography; but it is not within my province to discuss them, as they are but the preliminaries, the beginning, of which topographic surveys may be said to be the con-

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summation. The student of topography, however, may profit by acquiring a knowledge of the development of geography. He will not proceed far in his researches before he will be impressed with the great loss of time and labor that has been incurred in rectifying the errors of explorers and geographers. It is true, that, in the earlier centuries, and we may say even to within a century past, those who sought new conquests in the field of geography did not have the means of locating their discoveries with the precision that can be attained by modern methods, and that inaccuracies and misconceptions necessarily arose from the imperfect methods. But these are the errors most readily detected, as they are based upon observations that can be assigned a probable value. The more numerous class of errors, unfortunately, were not so readily adjusted; based as they frequently were on unverified reports, or sometimes simply the imagination, they have necessitated many perilous voyages and years of arduous effort to disprove them.

These difficulties have been experienced in delineating continents, oceans, seas, and all the grand features of Nature; and in recent years, in locating many of the works of man, especially cities that history teaches were once the pride of nations and the homes of a civilization of which the barest traces can now scarcely be found.

We are led to inquire, does history repeat itself? Shall the progress of our day be buried under the accumulations of centuries? Is the great American Republic to be traced by fragments of history and the legends of the age? Who can say, and is there one so bold as to predict what will come? We cannot control a future age, but this does not relieve us of the responsibility to ourselves and to those who come after us in whatever age, that the record we make of that which we have shall be true.

In topographic surveying, we continue the work of the explorer and geographer; the same areas are defined, but with greater detail; expression is given to all the features of Nature and the works of man. The results present to us a picture of wondrous forms in which we study the transformation of hills and valleys, the growth of rivers, and the surface resources of mother earth, in advancing economic problems involved in the progress of civilization. It is but a step more, with the aid of the specialist, and we reveal the treasures hidden in the rocks of the ages.

Topographic maps are valuable in military operations, to the student of geology, and to the engineer in the projection of railroads, canals, wagon roads, and all routes of communication between specified localities. They have special value in the study and development of economic questions: in a region to be opened for settlement they indicate graphically the most favorable localities to the pioneer; and when, in addition, they represent the character of the soil, woodlands and other characteristics, they may be recognized as authority in the projection of plans of colonization and development that cannot be surpassed. They are also valuable in regions that have been long settled, in perfecting plans for improvements that are not usually required in new districts; as, the conservation and utilization of water power for industrial purposes, improvement of roadways, extension of cities and villages, and planning many of those new enterprises that spring up with the advance of civilization. They are a necessity in the study of geology, and are valuable to students of many of the natural sciences, and frequently are essential to the ascertainment of correct results, and their intelligible publication.

Topographic maps, to meet these purposes, may be of varying degrees of accuracy, and contain more or less detailed information depending largely upon the characteristics of the region they represent. It is not necessary that a map of a new region should delineate the features with the greatest refinement; while, on the other hand, a region that has been long settled must be represented with an accuracy and detail that admits of no substantial error, to permit the work being used to advantage in the character of the improvements that arise under such conditions.

The principal nations of Europe have completed surveys that will generally subserve these purposes, or are now engaged upon such work. In some instances, the political conditions that have prevailed in the Old World necessitated cadastral surveys that were made with great accuracy. As a rule, this cadastral work did not represent the relief of the topography; but when it was found desirable to add relief to the artificial features, the cadastral work proved to be a basis that would control and facilitate the representation. These European surveys are based upon a precise triangulation, and are usually made upon a scale not far from 1:25000, sometimes slightly larger, and sometimes slightly smaller; excepting in mountainous districts, where the

scale is generally reduced to about 1:50000. In some instances, where the surveys have been inaugurated on smaller scales than 1:25000, the scale has been increased, to permit a generous treatment of the details. The Ordnance Survey of Great Britain probably stands unrivaled in point of accuracy and thoroughness. The work had been carried over a greater portion of the Islands on a scale of 6 ins. to the mile, when it was determined that a scale of 25 ins. to the mile would be more suitable for the purposes the survey was intended to subserve, and the survey of nearly all the fertile districts of England and Scotland has now been completed on this large scale. In this work little or nothing was left to the imagination of the surveyor; all lineal measurements are matters of record; all elevations have been controlled by accurate level lines; and bench marks have been left at frequent intervals for future use. These large scale surveys are the groundwork of all map publications, the details delineated in the original surveys being generalized or eliminated in the reduction to smaller scales, preserving generally only those features that can be clearly represented. The contour interval is 50 ft., though, in some instances, 25 ft. has been used on the large scales. The contours are published on some of the maps on the 1-in. and 6-in. scales, but are rarely given on larger scales.

The British have also extended their work to the Indian Empire in the establishment of the great Trigonometrical Survey of India, and have provided for topographic maps of great variety and value. There is a general topographic survey being conducted on the scale of 1 in. to the mile, supplemented in many localities by cadastral surveys on scales of 4 ins., 16 ins. and 32 ins. to the mile. This cadastral work is very elaborate, and it is stated by Captain Wheeler, in his Report on Government Surveys, that in the survey of the town and island of Bombay, about 22 square miles, the fields and open country were surveyed on scale of 1 in. to 100 ft., with the native town and fort on scale of 1 in. to 40 ft., the relief being shown by 10-ft. contours, at an average cost of $7 040 per square mile.

In the United States no consistent attempt was made to conduct a topographical survey over the whole area until the organization of the Geological Survey, about 15 years ago. Nevertheless, a large amount of work has been done in delineating the natural features with sufficient accuracy to prepare geographic maps, and in some sections

topographic maps, of a high order. The first work of the General Government in the development of the Territories, and which has produced the largest amount of geographic information, was the organization of the Land Surveys, for the division of the public lands into township sites. These surveys supply very little topographic information; they traverse the streams, but rarely furnish any indication of the relief of the topography or the artificial details.

The second organization was the establishment of the Coast Survey early in this century, although the work did not assume definite proportions until 1832. Some 40 years later this survey was charged with the extension of its geodetic work across the continent, and with the determination of trigonometrical stations in those States that required their use in the prosecution of geologic and topographic surveys within their own borders. The topographic work resulting from the operations of this bureau is confined to a narrow strip along the coasts, rarely more than three or four miles in width. The surveys were made upon scales of 1:10000 and 1:20000; and having been designed for the double purpose of producing charts for the benefit of commerce, and maps for the public defence, embrace all the natural and artificial details that can be clearly represented. The earlier surveys were very defective in the delineation of details; but as the work progressed, improvements were introduced in methods that brought it up to a high standard. The survey of the Great Lakes under the Engineer Corps of the Army, established in 1841, furnished topographic maps of the shores of the Great Lakes similar to the later work upon the coasts. The original surveys by the Coast Survey are now nearly completed, and the original work upon the Great Lakes has been published for some years.

During the period in which these established organizations were prosecuting their labors on the coasts and Great Lakes, many explorations were conducted in the Territories, under the direction of the Corps of Engineers of the Army. The list of these exploring parties is a very long one, and as the results were mainly of a geographic character, although of great value at the time, they have little bearing on topographic surveys in general.

In the last thirty years there have also been a number of surveys organized for the development of special regions in the Territories that have resulted in the production of preliminary maps of specific topographic value. Among these were surveys by King, Powell, Hayden

and Captain Wheeler of the Army. These surveys represent little more than the mountain ranges, mountain passes, principal streams and valleys, but omit so many details of these features in the generalization that was resorted to, that the value of the work falls below the standard that should be attained in topographic surveys designed to subserve general purposes.

Incidental to work in the Interior, the operations of the Mississippi River Commission, established in 1876, and subsequently the Missouri River Commission, may be mentioned as furnishing a basis for further developments in the valleys of these great rivers. The courses of the streams have been triangulated, and a strip of topography obtained along either bank of the Mississippi River, representing the features in great detail. Similar work has been conducted on the Missouri River, but not with the same care in reference to details.

The Geological Survey, established in 1878, has extended its topographic work to nearly every section of the Union. In the Territories and Western States the omission of details of the natural features subjects the result, in a measure, to the criticism applied to the independent surveys that preceded it in the same regions. In the Eastern States, especially in those surveys conducted in co-operation with the State governments, there is a much fuller representation of both the natural and artificial details; the detail is more complete also in those States where the land has been subdivided by the Land Office; but under the general rules adopted by this bureau to omit all artificial features not clearly of a public character, and all wood outlines, there are many details of value to settled communities that are not represented.

This brief review of the topographic work in Europe and the United States leads us to consider what is yet to be accomplished in our own country, to supply us with general topographic maps that shall be of the greatest value. Heretofore our surveys in the Interior have been executed without a standard of comparison. The general scheme of the work has, perhaps, been prescribed to the surveyor, and in some instances the character of the details that he should represent or omit; but the selection of the details and the relative accuracy of their representation has generally been left to so large an extent with the individual on the ground, that we frequently find incongruities, and are greatly misled in interpreting the maps. To secure the production of uniform

work from many hands, it is essential that there should be a criterion to gauge the sufficiency of the surveys. A criterion has been formulated by a conference of topographers that assembled about a year ago at the Coast and Geodetic Survey Office in Washington by direction of the Superintendent of that Bureau, to define certain matters relating to topography falling under his own supervision. In the investigation of these subjects, the inquiries that were made included the work of European governments as well as that of our own Government. The material collected furnished data that suggested the propriety of formulating rules to govern the representation of the details of a region on a specified scale. While it is not the expectation that these rules will meet with universal approbation, it is believed they will indicate the requirements desirable to produce uniform work, and will lead to a consideration and discussion of the questions involved that will ultimately result in the adoption of a criterion that will be acceptable to all.

The problem presented some peculiar conditions arising from the general and specific purposes the surveys would be called upon to supply. There has been contemplated since the organization of the Coast Survey the probable extension of its topographic work, to such distance from the coast as would meet the general purposes for military defence. The execution of topographic work with this specific object in view, as well as the details requisite for purposes of navigation, necessitated the division of the detailed rules prescribed into two divisions: first, relating to the coast, and second, to the interior. The coast topography, embracing only a narrow strip along the shore, has heretofore been executed with a care that presented every detail that could possibly be required for the double purposes of navigation and public defence. As the work shall progress from the coasts, it is believed that much of this detail can be omitted without any serious detriment, and, in view of the decreased scale that can be used, may even prove to be advantageous. As the coast division refers to work to be executed for specific purposes, reference will be made to the rules for general topography of the Interior only.

All topographic work is to be based upon a computed triangulation. Experience has demonstrated this to be essential for preserving distances and directions over extended areas; small areas may be covered with graphic triangulation or filled in by direct measurements and be

properly checked by the computed triangulation surrounding them. All natural features will be delineated with greater or less accuracy depending upon their importance in the type, and a selection is made from the artificial features governed by their character and prominence; thus all roads that are open to the public, or that are used as highways, and all buildings that are on prominent locations will be indicated; while private farm roads, temporary wood trails, and, generally, fences will be omitted. The surveys should be made on a scale of 1:30000 with the exception of mountain types and flat areas with little natural detail, for which 1:40000 is recommended. The Conference was strongly of the opinion that 1:40000 scale was the smallest on which a reliable representation could be made under the rules that were formulated.

In considering types for the interior work, New England was selected as representing the greatest variety of natural and artificial detail. Rules for this type were prepared, and were taken as a basis for all other types, receiving such addition or modification as was found desirable. Passing over New England, a second type was found in the Allegheny Mountains, and other forms in the great Atlantic Coastal Plain, the Prairie Lands of the Central States, the Great Plains of the West, the Plateau Region of Kentucky and Tennessee, the Rocky Mountains and southern part of the Sierra Nevada, and finally the densely wooded Sierra Nevada of the North. These types of country have been designated by proper names, and rules formulated to govern the detailed representation of each. There is no feature, either natural or artificial, that can be fairly claimed to be common to all these types of country, and yet there are many features that are common to several of them. This distribution of the details that require representation renders it quite evident that no universal rules can be prescribed, and that a criterion to judge the sufficiency of any one type would probably be unsuitable to judge any other type. Additional complications will arise where two or more types are found in the same region; there may, therefore, occur a question where dividing lines are to be understood in representing two types on the same survey; but such questions seem unavoidable.

The instrumental methods to be employed on the surveys are also important factors. The Conference indicated its preference in methods for the different types; but methods must necessarily be modified by special conditions that may control at the time, and the ability and

training of the surveyor who may be engaged to perform the work in the field.

The natural features that it is desirable to represent on a general topographic survey may be classified as hills, valleys, plains, water-courses and woods; and the artificial features as roads, water-ways, settlements and domiciles. These classes may be further subdivided in ways that will naturally suggest themselves. The rules to govern the selection and location of these features constitute the criterion. There is no rule that can be applied rigidly to all types; but the principles involved in the rules are nevertheless of general application. The roads and water-courses usually form a framework on which to represent the other details of the survey. They may be treated under a general rule requiring a close approximation in their location, but permitting considerable latitude in less important localities. Generally, crossroads are to be shown in their true position, and no part of a public highway will be more than its width out of its true position. With less important roads, like those through forests, or by-roads, a larger error may be permitted—perhaps 50 or 100 meters in some instances. With the water-courses, the general system to be applied is great accuracy where the streams join, and increasing latitude as the importance of the streams decreases. In some instances, the width of the stream may be increased or diminished by small quantities, and for unimportant brooks passing through woodlands the general direction only is to be maintained, sinuosities of the brook being entirely ignored. A similar brook, however, passing through open land, requires that its course should be more closely delineated. Cities, large towns and compact villages are to be represented in a conventional manner, the streets to conform as nearly as practicable to the true plans. This preservation of the plan is the more important in straggling villages where a difference from the true plan is liable to mislead. The houses of a settlement are of so little value as a feature that they are entirely neglected; but in the open country houses frequently become landmarks, and it is therefore provided that the most prominent domiciles and even barns, when isolated, should be represented with the accuracy required for other fixed points. In a group of domiciles, however, or when situated in localities where they do not attract great attention, their precise determination is of so much less importance that the greatest accuracy is not required; the location of

a house, barn, or other structure in a forest is desirable, as buildings in such locations indicate definite measures of distance and identify localities; if near a road, they are to be represented in connection with the road, and would be governed by the same rule of precision as the road. Water-ways constructed by man follow the general rule for the location of the roadways. They are of great importance in some regions, especially where agriculture is maintained by irrigation, where they have been constructed for the supply of water for large cities or intercommunication between definite points.

The relief of the topography bears directly upon all these details. In modern practice the hills and valleys are delineated by lines representing planes of elevation, called contours or curves of elevation, a uniform height being interposed between each plane. This system presents the most valuable data, but may frequently lack force of expression. The alternative system of hachures, or the representation of grades by lines of shading from vertical, or in some instances oblique light, gives a more striking expression on a small scale, but utterly fails to furnish the valuable data that may be derived from contours. There are many accidents of Nature, however, that would not receive attention in any system of contours it is feasible to extend over a large area; these the criterion provides for in a combination of the two systems. The general elevation and form to be shown by the contours, and the intermediate features of sufficient importance to require expression that the contours would not include, to be added in hachures. The necessity for this may be exemplified in the representation of any mountainous region, with a contour interval of 100 ft., or, as may in some cases occur, 150 ft., where the general slope, without any attention to minor details or breaks of the ground, would be shown by a gradual rise, practicable for the ordinary means of locomotion; but between these intervals there may occur precipices, ledges, gullies and other features that would make a passage-way most difficult if not impracticable. These features would be represented by hachures on the contours, and give an expression to the difficulties of the ground that will rarely be misunderstood.

For the New England States, and, in general, through rolling country, the contour interval of 20 ft. has been found to give great satisfaction, and rarely fails to represent the essential details of the natural features. This interval has, therefore, been recommended for

the New England type, and is taken as a unit, so far as practicable, for all other types.

The heights of the hills are to be given within 5 ft. of the true elevation, and, in general, the crests and floors of the valleys are to be represented quite as closely. The curves, showing the slope, can be sketched with greater freedom, but should not be in error more than the curve interval. Auxiliary curves may be used to form marked features falling between the prescribed contours; but when such features can be delineated by a slight deflection of the regular curve of not more than 5 or 6 ft., it is desirable to represent them by this means, rather than by the introduction of auxiliaries. In mountainous regions, the rules give still greater latitude, the representation being governed, as before, by the curve interval, but the interval being five or six times as great. It is not contemplated, however, that these great intervals shall be carried over the foothills and rolling country at the base of mountain ranges, as they would fail to give that minute description of the smaller features that is desirable.

It is evident that with the relief represented in this degree of detail, the grades of the natural water-courses and the elevations of small lakes and ponds would be fairly well determined; the natural basins would also be delineated with an accuracy that would permit a close computation of their capacity, and it would only be necessary to gauge the streams to determine very closely the water-power available for industrial purposes and for the supply of cities and towns.

The wood outlines were conceived to be a feature that required representation, though not with such accuracy as fixed features; the outlines are subject to change, especially in newly settled regions; but in the older districts the liability to change is not nearly so great, and in general the wood areas represent in these districts the principal localities that are not so available for agricultural purposes. Again, in the western country, where large tracts are almost destitute of trees, the representation of the growth that is found is of great importance, perhaps as indicating the presence of water, or as forming a prominent landmark. Instances of this kind would naturally be represented quite closely in their true position and extent; but in regions where wooded growth is common, an outline true within 50 or 100 m. would be considered sufficiently precise.

Topographic maps, made on the principles laid down by the Conference, would probably subserve all general purposes. The practicability of completing such a survey within a reasonable period, and at a reasonable cost, will, doubtless, be raised as an objection to any such project. The time required would very largely depend upon the sum of money that would be available for its prosecution. With an unlimited supply it might be possible to train a sufficient number of surveyors to complete the whole area of the United States within a generation; but it is not probable that such haste will ever be necessary. Maps of this character, however, would be found so valuable in economic questions that all work executed for general topographic purposes should be gauged by a standard at least as rigorous.

It is exceedingly difficult to determine the cost of work that is the continuation of surveys that have been in operation for many years. There is always a tendency to improve—to take in some new feature or omit some feature that has heretofore been represented—and these changes may increase or diminish the cost to such a degree that the average results for long periods become totally unreliable. Moreover, the same character of work executed by different men will present different rates according to the capacity and experience of the individuals. Captain Wheeler, in his admirable report on Government Surveys, ascertained the approximate cost per square mile of the principal surveys of the world. He states his experience in endeavoring to secure data of this kind, and expresses the opinion that his results must be considered merely as estimates, though probably the best that can be prepared. Some of these estimates are very interesting.

The average cost of the Ordnance Survey of Great Britain up to 1881 is estimated at $186 per square mile; but it was thought that the surveys on the scale of 1:2500 when completed would exceed these figures, and probably reach about $244 per square mile. In the German Empire, on a scale of 1:25000, the work has cost about $79 per square mile; and in Austria work on the same scale of 1:25000, including the office operations, has been estimated to cost about $400 per square mile. The cost of revising work in Holland, on the scale of 1:25000, is put down at $16.50. In India, the work on a scale of 1 in. to the mile, taking the average for 10 years, cost $11 per square mile; the work on 2 ins. to the mile was $26, and on 6 ins. to the mile, $400 per square mile, without the cost of printed maps. The survey of Bombay, on

very large scales, as before noted, cost $7 040 per square mile. There is probably more confusion in these figures than appears on the surface, as questions relating to services are not clearly stated, such as the pay of officers in the regular employ of the different governments; services rendered by detachments from the military forces; incidental office expenses, and items of that character. These figures indicate, however, that the best experience of European governments requires an expenditure considerably larger than it has ever been thought prudent to expend upon any of the interior work of our own country. Probably the greatest cost per square mile of topographic work in the United States, aside from the surveys on the coasts and Great Lakes, and other specific surveys of a like character, has been made by the U. S. Geological Survey in the work undertaken by that Bureau in connection with the State governments; and as the accounts have been kept separate from other expenses, they differ from the usual statements relating to cost, and furnish reliable data for work of this character. The average cost in Massachusetts was $13 per square mile; in Connecticut, $9.80; and in Rhode Island, $9. These surveys were made on a scale of 1:30000, which presents very generally the same facilities for representation as the general European scale of 1:25000. Other topographic surveys by the Geological Survey of the same class of work, especially in the west, owing to the type of country and facilities afforded by the marks of the Land Survey, cost very much less than these figures and the estimate for the average cost of work throughout the whole of the United States, without Alaska, does not exceed $4 or $5 per square mile.

The topographic work of the Mississippi River Commission is more closely allied with the detailed surveys recommended for the Interior. The cost of this work per square mile is therefore a nearer approximation of what would be the probable cost of detailed topography. The report of the Commission specifies an area of 819 square miles surveyed, 182 square miles of which, however, was hydrographic work of the Mississippi River, at an average cost of $48 per square mile. Also that 1 135 square miles previously surveyed cost $57 per square mile. It is not clear whether the latter item includes any hydrographic work or not. The topography of the Coast Survey and the Survey of the Great Lakes was made on so large a scale and involved intricate details of shore line and other coast features not found in the Interior, that so

greatly enhance the cost that they cannot be directly compared with any other surveys in this country. General Comstock reported that the average cost per square mile on the survey of the Great Lakes was $151. This probably includes office expenses and many incidentals that would not appear in ordinary field accounts.

Several attempts have been made to ascertain the cost of topographic work on the Coast Survey, but it is so frequently involved with expenditures for triangulation and hydrography that it is exceedingly difficult to compute an average for any lengthy period of time. A late Superintendent pronounced the survey of Mount Desert Island to have been among the most costly; yet the expense for the topography he stated was only $97 per square mile. There are, besides, many instances that could be cited where the cost ranged from $60 to $75 per square mile for work on the New England coast, and $10 to $15 on the southern coasts. Referring, then, to the operations under European governments and under our own, exclusive of work on the coasts and Great Lakes, it seems quite probable that the survey of the whole United States could be conducted on scales of 1:30000 and 1:40000, giving the detail that has been outlined, and with the accuracy that is called for by the rules recommended by the Conference, at an average cost of from $35 to $45 per square mile for the most difficult and detailed parts of the work.

The topographic work that has heretofore been conducted by Government Bureaus, either abroad or at home, has shown a tendency to improve as the work progressed. The persons in charge of surveys of this character are naturally ambitious to increase the value of the work under their direction and introduce new features suggested by their own experience and the experience of those working under them, and by the criticisms of those who make use of the publications. Changes arising from these sources frequently involve the mode of representation, the scale of publication, and even the scale on which the original surveys are to be made, and sometimes have necessitated radical changes in the methods of making the surveys. In Europe cadastral surveys have been improved upon to produce topographic surveys; small scale work has been abandoned for larger scale work, and the general tendency has been to present all detail with greater accuracy than was originally contemplated. New instruments have been devised in the hope of accomplishing this without unduly increasing the

cost. Improvements of a like character have been made in the United States; the early explorations and geographic surveys of the western territories have been superseded by an organized topographic survey, which, in turn, has developed its methods, to delineate more closely the features represented, even enlarging the scale for some types that experience has demonstrated required a larger scale to bring out greater detail of the features.

The improvements that have been made in the topographic work of the Coast Survey probably exhibit the development of such work more clearly than will be found in any bureau of the Government service. The history of the development of our methods is interesting and has not heretofore been published.

At the practical beginning of our work in 1832, we had as a guide only the experience of a few men who had practiced topographic surveying in the Old World, and reliance seems to have been placed without question on the sufficiency of the methods they introduced. Their methods were continued in the actual work of the survey for some 10 or 12 years when suggestions from a young officer produced the first change, which has led by gradual steps to the perfection that has now been attained. The plane-table has always been used on the Coast Survey in the topographic surveys, but the knowledge of the best methods of utilizing the instrument was so imperfect that the surveys did not acquire a high standard. The instrument was used principally as a substitute for the surveyor's compass ; the advantages to be derived from using it as a triangulation instrument to interpolate graphically subsidiary stations from a computed triangulation having been at first almost entirely ignored. The delineation of the topographic features resulting from these imperfect methods was necessarily defective ; the hills were represented by hachures sketched with the greatest freedom ; the shore line presented only the most salient points with any great degree of accuracy, the bights and coves being sketched with almost the freedom of the hill work. The artificial features were proportionally defective and sometimes aggravated by a system of representing the cleared lands suitable for agriculture, by a confusion that drew imaginary fences over the whole area. The first great improvement was in the method of using the plane-table. The theory of the instrument was, of course, well understood ; but the practice had evidently been greatly neglected. The three-point prob-

lem, as it is called, or the graphic method of finding a position from three other determined positions, was brought forward and utilized in securing more accurate determinations of the sketching stations. The second step was a more precise delineation of the form of the hills, or the relief of the topography, which was soon followed by an effort to give absolute elevations as well as forms. Some of the young topographers, in following the old system of representing the hills by hachures, had found it convenient to first shape the hills with parallel lines, or contours as they were then called, though not representing planes of elevation as our curves do in the present day. By means of these contours they easily saved the time consumed in the field in drawing the hachures, relegating the labor of hachure-drawing to the office after the completion of the field work. It was only a step from contours to curves of equal elevation; these were soon proposed by one of the young topographers who had been using contours to shape the hills, but, being an innovation, seems to have met with decided opposition. Permission was granted, however, for him to try his scheme of representing the forms of hills with lines showing approximately every 20 ft. of elevation, the hachuring that might be subsequently required in publication to be executed by a draughtsman. At first the curves of elevation depended entirely upon the eye of the topographer for their distance above water level, and were looked upon as simply a new method of representing the forms of the hills, or a substitute for hachures. Up to this time the elevation of the hills had not been ascertained; the simple fact that here there was high land, with the approximate form and area, was all that was recorded. But the curves of elevation were found to be so much more convenient, and represented so much more clearly the relief, that the attempt was soon made to determine the elevation by actual measurement, and for this purpose a small, vertical arc was added to the alidade of the plane-table. This addition to the alidade was so effective and reliable that it is still in common use.

The system of representing the relief of the topography by curves of equal elevation was discussed in Europe in the early part of the century, the discussion running for a period of 20 years, and with such earnestness that it became known among topographers as the "Twenty Years' War of Hachures and Contours." The victory seemed to be for a time with the advocates of hachures; but the evident advantages

of the contour system finally prevailed, and between 1840 and 1850 it was receiving very general recognition. It is merely a coincidence that about this time the same system was developed by American topographers on the work of the Coast Survey, and, as the writer has every reason to believe, without any knowledge of the discussion that had long continued in Europe.

The method of topographic work on the Coast Survey had now reached a development that required only experience on the part of the topographers to produce results of ample refinement for the purposes of the survey; but subsequent demands on the Bureau for special surveys, with the requirement, in many cases, that the curves of elevation should have the same relative accuracy as the artificial features represented upon the maps, necessitated a modification in the details of the system of work, and the introduction of auxiliary instruments. These were supplied on large scale surveys, where this increased accuracy in the relief was demanded, by running out each contour with a surveyor's level from established bench marks, and determining each position of the leveling rod on the plane-table sheets at the same time. Numerous surveys of small extent have been made in this manner, and recently there has been completed a topographic survey of the District of Columbia, embracing about 60 square miles on a scale of 400 ft. to the inch, that is doubtless as accurate and thorough a piece of work as has ever been executed over such an extended area on so large a scale. It has been severely tested by the engineers of the District Government and by civil engineers interested in the subdivision of suburban property, and has uniformly been accepted as work of the highest order. It represents every detail upon the surface, with contours for every 5 ft. of elevation, reaching a maximum height of over 400 ft. These contours develop the cuts and fills in the roads, gullies and similar features with great accuracy.

In considering questions of topographic surveying, we must not confound the general survey with surveys for special or specific purposes. The general survey may simplify the projection of special work, but can in no sense supplant it except for general purposes. To determine the exact line for a railroad or canal, or to furnish the data for computing the labor of constructing a dam, and for other similar purposes, the special survey will always be required; but it is true, also, that in a general survey the local conditions and the most prob-

able uses of the work may properly receive consideration. In a region with an abundant water supply we would naturally omit giving attention to problems of irrigation; while, on the other hand, in regions where a natural water supply is deficient, we would pay the closest attention to the delineation that would exemplify the resources of the region for irrigation. Again, great mountain masses would be greatly generalized in a region that is difficult or perhaps impossible of access, while the passes, and the approaches to the defiles, would receive such careful attention that their availability as routes of communication would be thoroughly portrayed.

The most advisable form for the publication of a topographic survey should depend upon the character of the survey and the special purposes the publication is intended to subserve. The first conditions, therefore, to guarantee publications of the greatest value must be the faithfulness of the field work and its original representation on a sufficiently large scale to show the details clearly. A base map of this character can be reduced to smaller scales, and still preserve the essential details for general purposes; can be copied on the original scale; or, if need be, enlarged for special purposes, and can be generalized for geographic purposes. In each case the information conveyed would be reliable, measured by the scale and modified only by the faithfulness of the surveys. An argument is not needed to present the usefulness of trustworthy maps. Few men engaged in the active enterprises of the day have not experienced the demand for them, and we may safely predict that, as our people advance in prosperity, the demand will come from the masses. Already in some of the older States the demand has taken form, and other States are knocking at the door. Such surveys are essentially national; they benefit all communities in enlarging the horizon and bringing before the people knowledge they can attain in no other way; although it is true also that some particular communities may gain the greater benefit for the time being. It may be right, therefore, that the expense for such work should be borne jointly by the National and State governments; but to secure uniformity it is essential that the surveys should be supervised and conducted by men trained for the purpose; that the experience gained by the first who undertake such work shall be transmitted to their successors by contact and practice. One bureau of the National service is now authorized to co-operate with the States and furnish geograph-

ical positions; another is engaged upon a topographic survey for geologic purposes, and at the request of some of the States has jointly with them improved its topographic work within their boundaries to the extent the joint appropriations would permit. But the results thus far produced by the surveys that have been made in the Interior do not meet the requirements of a general topographic survey: either the work has not been supported by sufficient means; the attempt has been made to accomplish too much in too brief a time, or the specific purpose held in view has restricted the operations to an extent that prohibited the treatment required by a general survey. It is quite possible some of the older States will soon meet with economic problems that will force them to obtain maps with a more generous supply of information, and we may feel assured that, when the advantages of such maps have once been demonstrated to our people by actual experience, they will fully appreciate them and incite a demand for their extension. The day, the writer believes, is not far distant, when we must seriously consider the best means of conducting topographic surveys in all the States that will insure us the most valuable results for the expenditure. There can be no doubt that all the maps should be directly comparable; that while some might have a superior excellence, there should be none that would fall below a certain standard. The reputation for reliability attained by the surveys on the coasts, purely the result of providing by law the objects the work was to subserve and the methods that should be employed, leads the writer to believe that, to secure the desired harmony of results in all the States, the surveys should be conducted under rigorous rules, prescribed in a National law.

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RECENT EXPERIENCE ON THE U. S. COAST AND GEODETIC SURVEY IN THE USE OF LONG STEEL TAPES FOR MEASURING BASE LINES.

By R. S. Woodward, C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Introductory and Explanatory Remarks.—Few if any appliances in the art of measurement on the surface of the earth are of higher antiquity or greater utility than the metallic chain, now commonly called, among English-speaking peoples, the surveyor's or Gunter's chain. No appliance is more widely or better known than it, and none meets with more general appreciation. The compass, a much later invention, to which the obscure property of magnetism adds an element of mystery, is undoubtedly an instrument of more profound interest to the curious and thoughtful; but the greater antiquity, the incomparable simplicity and the more general usefulness of the chain entitle it to the place of first historical importance in any enumeration of such ap-

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pliances. To the surveyor whose measurements determine the metes and bounds of properties, to the property owner who must depend on such measures, and to the jurist who decides between conflicting interests, the chain has long been and still is the most common unit of definition and limitation.

Simple and effective, however, as the chain is in its way, it fails to meet many of the demands of the more refined work of the present day. With the growth and consequent complication of property interests, there arose a need for increased precision in the definition of distances. And as the engineer has succeeded the surveyor in such higher grades of work, so have other devices taken the place of chains. Among these devices the most important as regards general utility are metallic tapes and wires. The adaptability of tapes, especially, to a wide range of measurements is now well known. Indeed, their use has become alike indispensable to the engineer, the architect, and the artisan. The superiority of the tape over the chain, when precision is in question, is manifest. The defects due to the numerous links and joints of the chain are overcome by the continuity of the tape; while the advantage of pliability secured by the joints of the former is met by the elastic flexibility of the latter. Hence the tape must be considered the natural successor of the chain; and in any scale of relative usefulness and precision the tape, as ordinarily used, must rank next above the chain.*

In many, if not most, of the applications of linear measures it suffices to ignore the effect of heat in changing the lengths of our standards. When we take this effect into account, however, the order of precision attainable is greatly increased. This fact has long been adequately recognized with reference to bars used as standards of lengths; but that the same heat-effect constitutes the principal factor of length change in metallic tapes and wires seems to have been rather tardily appreciated; for, although the art of wire-drawing dates from the latter part of the fifteenth century, the art of using a wire or tape in measures of precision is hardly more than two decades old. Within this latter period many persons have independently entertained the idea of using long tapes and wires for the more refined work of geography and geodesy. The credit of calling distinctive attention to the availability of tapes and wires in such work appears to belong to Prof. Edv.

* It appears that metallic tapes were invented and introduced by J. C. Chesterman, to whom Letters Patent were granted by the English Government in 1842. He had previously patented measuring tapes made of cloth or other fabrics in 1829.

Jäderin, of Stockholm. His researches began in 1878, and his memoir,* published in 1885, in which he gives a full account of the theory and results of his measures, has been an important guide to subsequent investigations. The essential fact developed by Jäderin, and the fact on which attention should be concentrated in considering this subject, is that the temperature of the tape or wire is the most important factor in determining its length. When this fact is recognized, it becomes evident that if means can be devised for getting that temperature, the tape combines the advantages of great length and simplicity of manipulation of the chain, along with the precision of the shorter or laboratory standards.

It is the object of this paper to give a brief account of the recent experience of the writer in the use of long tapes for measuring base lines in the primary triangulation of the U. S. Coast and Geodetic Survey; to explain the processes developed in this work, and to give such results as will enable the reader to judge of the merits of the method for geodetic work.

The investigation of the practicability of using long metallic tapes for measuring lines of precision was taken up by the Coast and Geodetic Survey in the autumn of 1890. This work was assigned to the writer, who conducted the preliminary experiments and devised the apparatus described herein. In all of this work very efficient assistance was rendered by Mr. J. S. Siebert, who made most of the working drawings for the construction of the apparatus and participated equally in the large amount of observation and computation entailed.

Steel tapes 100^m long were used during the summer and autumn of 1891 to measure the Holton Base, Ind., a line in the Transcontinental chain of primary triangulation. The five sections of this base (of $5\,500^m$) were measured from 6 to 30 times each, under various circumstances as to temperature, time of day, etc. In the following year, viz., October, 1892, another base (of $3\,900^m$) at St. Albans, West Va., in the same chain of triangulation was measured. The results for this latter base are given below.

Mercurial thermometers were used in all these measures to determine the temperature of the tape. An attempt was made in 1891 to use a bronze tape in connection with the steel one for temperature in-

* Geodätische Längenmessung mit Stahlbändern und Metalldrähten. Von Edv. Jäderin. 8vo, 57 pp., 2 plates. Stockholm, 1885.

dications; but the bronze tape was found to have too low a rate of expansion for successful competition with the mercurial thermometers. The feasibility of stretching two tapes simultaneously was demonstrated, however, and if a suitable metal for use with steel can be found it may prove advantageous to discard the mercurial thermometers.

During the winter of 1890 and 1891 a great number of experiments were made with a view to determine the best method of stretching and aligning a tape, and especially with a view to discover the most effective way of getting the tape's temperature. For this purpose a 100^m comparator was set up in the Botanical Garden at Washington, D. C. This comparator consisted simply of a series of equi-distant stakes, 10^m apart, bearing support nails for the tape, and a post at either end on which were attached scales for defining the tape's position at any time. These preliminary experiments served to fix attention on most of the points essential to the use of tapes in precise measures.

Description of Apparatus and Methods of Use.

The 100^m *Tapes.*—These tapes are of steel. They are 101.01^m long, and are 6.34^{mm} x 0.47^{mm} in cross-section. They weigh 22.3 gr. per meter of length. They are subdivided into 20^m spaces by graduations ruled on the surface of the tape itself. Being 101.01^m long, the end graduations fall about 0.5^m from the tape ends, which terminate in loops formed by annealing and riveting the tape back on itself. The surface of the tape, where it is not polished to receive the graduations, is of a dull black color. When not in use the tapes are rolled up on reels, and they may be thus transported with ease and safety.

The Tape-Stretchers.—The nature of the tape-stretchers used to give tension and alignment to the tape may be best understood by a glance at the accompanying cut. They consist of a lever hinged by a universal joint to a platform on which the operator stands. This lever is made of a piece of steel tubing terminating in a hickory handle. Along the upper two-thirds of the tube is cut a screw-thread on which a wheel-nut plays freely. This nut gives a vertical motion to a gimbal-jointed support to which a spring balance is attached. The balance is connected with the tape by means of a short piece of sash chain. It is evident from the figure that the stretcher has all the motions necessary to enable the operator to align the tape and to give it the proper tension.

The balance, which is simply a commercial article adapted to the purpose, reads to ounces, and may be easily held to the nearest ounce by the operator.

An important item for the safety of the tape used is a breaking link, or a link which will part under a tension of about 14 kg. or 30 lbs. A link of this sort is provided at each end of the tape, so that it cannot be overstrained by accident.

It will be noticed that the balance carries two hooks. The extra hook, which is attached to the balance frame, was intended to carry the additional tape in case it proved advantageous to use tapes of different metals simultaneously. This plan of stretching two tapes worked very satisfactorily, the tension of the steel tape being given by one balance, and that of the bronze by the other; but for the reason stated above, this plan was followed only in making a few of the tape comparisons mentioned below. The extra hook, it may be stated, is provided with a longitudinal screw motion, so that by means of this and the links of the connecting chains the tapes may be always brought to the proper tension whatever their temperature.

When a single tape is used, the rear end is attached to the extra hook of the rear end balance, while the desired tension is given by the balance at the front end of the tape.

An objection to this form of stretcher lies in its weight, which is about 45 lbs. Contemplated improvements will lighten it by several pounds and bring the balance to a position concentric with the lever shaft. Experience has shown, however, that an able-bodied operator can handle the stretcher successfully when measuring at the rate of 2 km. per hour. During the measurement of St. Albans Base, in 1892, 8 km. were measured on one occasion between 7.30 P.M. and midnight without excessive fatigue to the operators.

The Thermometers.—The thermometers used are of the Centigrade type and are graduated on their stems to half degrees. They were made by Green, of New York. They were originally mounted on brass scales. The preliminary experiments showed that the mass of these scales caused the thermometers to lag very considerably with respect to the tape temperature. Hence the scales were removed, and light wire loops were attached to the upper ends of the stems, so that the thermometers could be suspended by a cord and thus isolated from adjacent masses or whirled in the air when necessary. Experiments also showed these thermometers to be slightly more sensitive when the bulbs were covered with sheaths of blackened aluminum foil, though this increase, if real, is probably unimportant. During the measurement of St. Albans Base, in 1892, the aluminum sheaths were replaced by steel sheaths, made by coiling and annealing very thin steel tape into lengths just long enough to slip over the bulbs and clasp the thermometer stems. These are undoubtedly superior to the aluminum

sheaths in simulating the surface of the tape, but they are of somewhat greater mass than the aluminum sheaths and cause more lag of the thermometers with respect to the tape. In any case it seems desirable to blacken the bulbs of thermometers used with steel tapes presenting a blackened surface.

A great number of experiments, made in the Botanical Garden during the winter of 1890-91, showed that with the thermometers arranged as just described (*i. e.*, with aluminum sheaths) they followed the tape temperature without serious lagging when observations were made under a clear sky at night. Subsequent experience in determining the tape lengths on the 100^m comparator of Holton Base showed a very satisfactory accordance of the tape and thermometer temperatures, whether observations were made during the day or night. This comparator was covered, however, except on its north side, by a shed which screened the tape from the direct rays of the sun. The results of these determinations of length are given in detail below, in Tables Nos. 1 and 2.

A striking fact brought out by repeated measures of the sections of Holton Base on cloudy days is that at such times the tape temperature was persistently higher than that indicated by the thermometers. The cause of this peculiarity is not yet fully made out, though investigations are under way to discover it. The amount of the discrepancy in our experience has risen at most to 0.9° C., which is equivalent to $\frac{1}{110000}$ part of the tape length or distance measured.

Sometimes three of the thermometers were used with the tape, and at other times two. When three were used, they were placed one at the middle of the tape's length and one at one-sixth that length from either end. When two were used they were generally placed at one-fourth the tape's length from its ends respectively. For the most precise work, as in comparisons for determining the tape lengths, the three thermometers were each read twice, once just before and once just after the observations on the tape. The mean of the six thermometer readings thus made gave the tape's temperature with a probable error of about $\pm$ 0.2° C., equivalent to $\frac{1}{500000}$ part of the tape length, when observations were made at night or under the comparator shed.

Method of Supporting and Marking Position of Tape.—When in use for measuring a line the tape is supported at equal intervals of 10 or 20 m. throughout its length. The supports found most convenient, and

amply sufficient, are steel wire nails driven into stakes set at the proper intervals along the line. These nails are ranged into a straight line for any tape length by means of a small theodolite whose telescope axis may be brought to the right height at one end of that tape length.

The ends of the tape are supported by the tape stretchers, by means of which the tape is aligned over the marking stakes. The latter are stakes of scantling cut off or driven down to the proper height and capped with a small table on which a plate of zinc is held in place by light nails. These tables and plates are rectangular, 5^{cm} x 20^{cm}, say, and the longer sides are placed parallel to the line. On the plates the position of the forward-end graduation of the tape is marked as the measure progresses by means of a sharp brad-awl held against the edge of a small try-square, which is aligned against the longer edge of the marking plate. The rear-end graduation of the tape is in turn brought into coincidence with the successive marks on the zinc plates.*

Operation of Measurement.—The marking and support stakes for the measurement of a line are most advantageously ranged out and adjusted beforehand. This is especially essential for work of the highest precision carried on at night. Assuming this to have been done, and that night work is contemplated, the operation of measurement, if carried on rapidly, will require 12 men, to wit: two observers of the tape, one at the front and one at the rear end; two observers of thermometers, who also help to carry the tape forward; one recorder; two operators of the stretchers; five men to handle lamps and to carry the tape forward.

The co-operation of the observers and other operatives is secured by means of a code of signals made with whistles held by the observers. Thus, when the observer at the rear end of the tape is ready to have the tension applied, he gives one blast of his whistle. The stretcher at the front end immediately brings his balance to the proper reading, when the observer at that end announces the fact with one blast of his whistle. With the tape under tension the rear-end observer adjusts the rear-end graduation of the tape to coincidence with the defining mark on the zinc plate at that end. When this is accomplished he gives two blasts from his whistle. On hearing these, the recorder,

* The use of such plates was introduced in 1885 by Mr. O. B. Wheeler, Assistant Engineer Missouri River Commission.

who stands at the middle of the tape length, immediately lifts the tape a few centimeters from the support nail near him and lets it fall back. The effect of this is to make the tape straight and relieve it from friction on the support nails. When the vibration of the tape ceases, the rear observer gives one blast, which signifies that the position of the front end of the tape may be marked on the zinc plate. The mark is made by the front-end observer, who, on completing the operation, gives one blast from his whistle. Then the thermometer readings, which are observed while the mark is made, are called out to and repeated by the recorder. Finally, the rear observer sounds two blasts from his whistle and the tape and tape stretchers are carried forward to a new position.

The speed attained in this process has been about 2 km. per hour, though a single kilometer has been measured in 20 minutes.

By reason of the expansion and contraction of the tape, it is frequently desirable to set the tape back or forward by a round number of centimeters. This may be done on the zinc plates by means of a suitable pocket scale. Such displacements are recorded as "set-backs" and "set-ups." Their amount is engraved on the plates, which may be appealed to if any doubt arise concerning the record. When "set-backs" or "set-ups" are made, and when more than one measure is recorded on the plates, it is advantageous to number, orient, and date them for filing as part of the records.

Determination of Equations of Tapes.

Data for Tape Lengths.—For the purpose of getting accurate lengths of the tapes and also testing their efficiency in the actual work of base measuring, a new form of base apparatus, known as the iced-bar apparatus, was devised by the writer. The essential feature of this apparatus, which is described in the *American Journal of Science* for January, 1893, is that the measuring bar is kept at a constant temperature by means of a packing of melting ice, thus avoiding in its applications the use of thermometers entirely. It is a line measure, micrometer microscope apparatus, and it appears to give a precision of measurement surpassing anything hitherto attained in base-line work.

The tape lengths were derived from numerous observations on a 100^m comparator whose length was determined by repeated measures with the iced-bar apparatus. The tapes were aligned and supported

on the comparator in precisely the same manner as when used in base measurement.

The details of all the work done up to date with the iced bar and with the tapes are now nearly ready for publication in the report of the United States Coast and Geodetic Survey. But since the character of the work done in deriving the equations of the tapes can be gauged adequately only by the results obtained, it is proper to anticipate that report to the extent of giving the essential details of the tape comparisons. The following tables give those details for the 100^m tapes Nos. 85 and 88 respectively. The first column gives the date of the comparison; the second, the time of day; and the third, the thermometric temperature of the tape in Centigrade degrees, corrected to the hydrogen scale. The fourth column gives the observed length of the tape in terms of the iced bar, the excess over 20 times that bar's length having been measured by means of micrometer microscopes and the millimeter scales of the cut-off cylinders accompanying the iced-bar apparatus. The standard tension of the tape is 11.595 kg., or 25 lbs. 9 ozs.; *i. e.*, it is the actual tension given to the tape when the balances used read 25 lbs. even. The last column gives the residual, or the difference between the length of the tape computed from its equation given below and the observed length.

TABLE No. 1.

Results of Observations for Length and Rate of Expansion of 100-Meter Steel Tape No. 85.

Date.	Time of Day.	Temperature of Tape.	Observed Length of Tape.	Residual (computed minus observed value).
1891.				
August 6th............	11.29 A. M.	29.02°C.	$20B_{17} + 35.51^{mm}$	$+0.12^{mm}$
	1.02 P. M.	30.56	37.69	− .34
	2.06	30.07	36.15	+ .63
	3.05	29.88	36.85	− .28
	4.02	28.92	35.14	+ .38
	5.00	28.01	34.58	− .06
	9.02	19.68	24.66	+ .63
	9.12	18.44	23.80	+ .25
August 7th............	7.02 A. M.	20.96	26.84	− .03
	8.02	24.53	30.84	− .13
	9.02	26.73	32.97	+ .15
	10.02	27.96	34.57	− .11
	11.01	29.26	35.95	− .06
	11.48	30.11	37.54	− .70
	2.04 P. M.	30.21	37.28	− .35
	7.16	31.35	38.47	− .29
	7.32	21.51	27.04	+ .37
	8.38	20.15	25.31	+ .60

TABLE No. 1—*Continued.*

Date.	Time of Day.	Temperature of Tape.	Observed Length of Tape.	Residual (computed minus observed value).
August 8th............	7.28 A. M.	24.66° C.	$20B_{17} + 30.43^{mm}$	$+ .43^{mm}$
	8.34	27.06	33.89	− .41
	9.35	29.14	35.89	− .22
	10.32	30.34	36.90	− .17
	11.31	31.39	38.39	− .17
	12.28 P. M.	32.12	39.23	− .21
	1.33	31.54	38.72	− .33
	2.34	30.32	36.77	+ .28
	7.41	21.48	27.10	+ .27
	8.34	20.93	26.56	+ .21
	9.34	20.38	26.20	− .03
September 5th.........	2.40 P. M.	14.88	20.20	− .05
	3.24	14.70	19.77	+ .18
	5.04	14.26	19.37	+ .10
	7.35	13.88	19.26	− .21
	9.08	13.98	19.12	+ .04
October 3d............	10.40 A. M.	26.73	33.25	− .13
	11.48	27.24	33.54	+ .14
	1.41 P. M.	27.06	33.38	+ .10
October 4th...........	4.54	13.85	19.41	− .39
	6.50	12.67	17.93	− .20
	8.08	12.32	17.18	+ .17
	8.58	11.70	16.85	− .18
	10.20	11.38	16.18	+ .14
October 5th...........	5.00 A. M.	7.20	11.66	+ .07
	6.04	6.66	11.19	− .04
	6.54	7.97	12.64	− .05
	8.04	10.24	14.71	+ .36
	9.00	11.80	16.54	+ .24
	12.38 P. M.	15.13	20.30	+ .12
	7.03	7.07	11.58	+ .02
	8.08	6.72	11.02	+ .20
	8.58	6.38	10.71	+ .13
	10.16	5.04	9.52	− .14
October 6th...........	4.32 A. M.	3.51	7.58	+ .12
	5.28	3.47	7.75	− .09
	6.28	4.76	9.01	+ .06
	7.56	9.59	14.23	+ .13
	8.54	11.95	16.78	+ .16
October 8th...........	7.54	8.62	13.50	− .20
	8.48	10.89	16.02	− .24
	9.52	12.55	17.96	− .36
	10.46	13.60	18.56	+ .19
	11.52	14.63	19.98	− .11
	12.58 P. M.	15.02	20.24	+ .06
	2.06	15.63	20.77	+ .20
	3.00	14.67	19.76	+ .16
	4.06	13.87	18.77	+ .27
	5.52	9.45	14.27	− .07
	7.12	7.38	11.83	+ .11
	11.16	7.25	12.04	− .24
	11.58	7.70	12.48	− .19
October 9th...........	2.04 A. M.	5.31	9.80	− .13
	3.04	5.49	10.05	− .18
	4.08	5.49	9.97	− .10
	5.06	4.19	8.76	− .29
	6.10	4.47	8.95	− .20
	6.56	6.68	11.38	− .21
	8.00	9.33	14.22	− .15

TABLE No. 2.

RESULTS OF OBSERVATIONS FOR LENGTH AND RATE OF EXPANSION OF 100-METER STEEL TAPE No. 88.

Date.	Time of Day.	Temperature of Tape.	Observed Length of Tape.	Residual (computed minus observed value).
1891.				
August 1st	10.14 A. M.	27.46° C.	$20B_{17} + 35.86^{mm}$	$+ 0.42^{mm}$
	1.52 P. M.	29.28	38.66	− .40
	2.50	24.96	32.94	+ .61
	3.32	24.61	33.48	− .31
	4.10	22.86	31.35	− .09
	4.56	23.34	32.41	− .63
	5.56	23.97	31.89	+ .58
	7.25	20.46	28.17	+ .46
August 3d	7.52 A. M.	14.99	22.73	− .06
	8.29	14.46	21.83	+ .26
	9.59	14.30	22.57	− .65
	11.05	14.70	21.96	+ .39
	1.32 P. M.	16.45	24.17	+ .09
	2.08	16.95	24.79	+ .02
August 4th	8.22 A. M.	20.84	29.12	− .07
	9.02	21.66	29.82	+ .13
	10.02	23.24	31.59	+ .08
	10.56	24.14	32.91	− .26
	12.02 P. M.	24.01	32.87	− .37
	1.02	25.01	33.60	+ .00
	4.46	24.77	33.03	+ .31
	9.04	17.72	25.16	+ .49
August 5th	7.15 A. M.	21.71	29.95	+ .05
	8.32	24.29	32.50	+ .32
	9.32	25.28	33.47	+ .43
	10.32	25.71	33.83	+ .54
	11.32	28.01	37.08	+ .21
	1.32 P. M.	28.01	36.99	+ .12
	2.32	28.27	37.03	+ .13
	3.32	27.89	36.60	+ .15
	4.30	26.31	34.74	+ .28
	5.32	26.27	34.88	+ .10
	8.56	17.67	25.06	+ .54
August 30th	6.46 P. M.	16.41	23.93	+ .29
	8.14	14.26	21.49	+ .39
	9.30	13.15	20.65	+ .01
September 5th	12.08 P. M.	14.55	22.58	− .39
	1.16	15.10	23.36	− .57
	1.42	15.78	24.09	− .56
	2.24	15.28	23.49	− .50
	3.45	14.28	21.96	− .06
	4.54	14.26	22.02	− .15
October 3d	10.55 A. M.	27.08	36.31	− .46
	11.39	26.99	36.44	− .67
	1.49 P. M.	26.93	36.44	− .74
October 4th	4.44	13.83	21.94	− .54
	7.02	12.60	20.16	− .10
	8.01	12.30	19.98	− .25
	9.10	11.53	18.92	− .03
	10.10	11.50	18.86	− .10
October 5th	5.12	7.03	14.15	− .18
	5.56	6.46	13.66	− .30
	7.00	8.25	15.37	− .06
	7.56	9.97	16.90	+ .29
	9.04	11.70	18.85	+ .23
	12.30 P. M.	15.35	23.05	+ .01
	7.12	7.02	13.71	+ .25
	8.02	6.42	13.27	+ .05
	9.08	6.54	13.42	+ .03
	10.04	5.12	12.03	− .13

TABLE No. 2—*Continued.*

Date.	Time of Day.	Temperature of Tape.	Observed Length of Tape.	Residual (computed minus observed value).
October 6th...........	4.42 A. M.	4.39° C.	$20B_{17} + 11.20^{mm}$	$- .10^{mm}$
	5.22	3.46	10.13	− .04
	6.34	4.66	11.29	+ .11
	7.48	8.82	16.12	− .18
	9.02	12.70	20.01	+ .16
October 8th...........	7.50 A. M.	8.15	15.57	− .36
	8.54	11.20	18.57	− .04
	9.48	12.14	19.44	+ .16
	10.52	13.85	21.24	+ .19
	11.46	14.05	21.10	+ .54
	1.04 P. M.	15.25	22.81	+ .14
	2.00	16.12	23.55	+ .35
	3.06	14.62	22.21	+ .06
	4.02	14.22	21.73	+ .10
	5.58	9.23	16.08	+ .20
	7.06	7.57	14.44	+ .13
	11.06	7.35	14.67	− .34
October 9th...........	12 08 A. M.	7.52	14.71	− .19
	1.56	5.39	12.57	− .38
	3.10	5.29	12.04	+ .04
	4.04	5.67	12.56	− .06
	5.12	4.21	10.86	+ .04
	6.04	4.11	10.84	− .04
	7.02	7.07	14.25	− .22
	7.56	9.10	16.71	− .47

Derived Values and Probable Errors.—Assigning equal weights to the observations in the above tables, the method of least squares gives the following equations for the tapes:

$$T_{85} = 20B_{17} + 22.35^{mm} \pm 0.023^{mm}$$
$$+ (1.0947^{mm} \pm 0.0025^{mm})\ (t - 16.89^\circ\ \text{C.}) \ldots\ldots\ldots (1)$$
$$T_{88} = 20B_{17} + 23.47^{mm} \pm 0.022^{mm}$$
$$+ (1.0914^{mm} \pm 0.0029^{mm})\ (t - 15.72^\circ\ \text{C.}) \ldots\ldots\ldots (2)$$

B_{17} = length of steel bar No. 17 in ice = $5^m - 16^\mu$ very nearly,

t = temperature of tape in degrees C.,

16.89° C. = mean of observed temperatures of tape No. 85,

15.72° C. = mean of observed temperatures of tape No. 88.

The probable errors of the mean lengths of the tapes and of their rates of expansion given above are derived in the following manner: The sum of the squares of the residuals for—

tape No. 85 = 4.82,

tape No. 88 = 8.62;

and since the number of residuals in the first case is 77 and in the other 85, the probable error of a single determination of length for—

tape No. 85 = $\pm\ 0.17^{mm}$,

tape No. 88 = $\pm\ 0.22^{mm}$.

Since there is no *a priori* reason for attributing any greater weight to the observations on tape No. 85 than to those on tape No. 88, the mean of these two values, or $\pm 0.20^{mm}$, is adopted as the probable error of a single determination of a tape length on the 100^{m} comparator. This error is $\frac{1}{500000}$ part of the tape's length. It is due almost wholly to imperfect temperature indications of the thermometers, since the means for referring the ends of the tape to the fiducial stones of the comparator would admit errors of a few hundredths of a millimeter only.

The weights of the mean lengths and the rates of expansion which result from the least square solution are for—

tape No. 85, 77 and 6 436,
tape No. 88, 85 and 4 687.

These, in connection with the probable error of a single determination of length derived above, give the probable errors attached to the quantities in equations (1) and (2).

Without attempting a full discussion of these results here, it may be stated that the above tables include every determination made of the tape lengths in question. The temperature range is from 3.5° C. to 32.1° C. for No. 85, and from 3.5° C. to 28.0° C. for No. 88. During the period covered by the observations, August 1st to October 9th, the tapes were wound on and unwound from their reels many times and used frequently to measure the different sections of Holton Base.

The maximum residual in the comparisons of tape No. 85 is 0.70^{mm}, and the maximum for No. 88 is 0.74^{mm}. These correspond to $\frac{1}{140000}$ part, about, of a tape length. The following table gives a comparison between the actual distribution of the whole number of residuals (162 for both tapes) and the theoretical distribution computed by means of the law of error of least squares.

TABLE No. 3.

DISTRIBUTION OF RESIDUALS.

Between Limits.	Actual Number of Residuals.	Theoretical Number.
0.0^{mm} and 0.2^{mm}	85	84
0.2 " 0.4	51	52
0.4 " 0.6	17	21
0.6 " 0.8	9	5

An inspection of the residuals in Tables Nos. 1 and 2 indicates that some lagging of the tape's temperature relatively to that of the thermometers occurred at times.

For practical applications the equations (1) and (2) may be written in the following more compact form:

$$T_{85} = 20B_{17} + 3.86^{mm} + 1^{mm}.0947\,t \ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$T_{88} = 20B_{17} + 6.31^{mm} + 1^{mm}.0914\,t \ldots\ldots\ldots\ldots\ldots \quad (4)$$

These equations give the lengths of the tapes when they are under a tension of 11.595 kg. (25 lbs. 9 ozs.), and when supported at equidistant intervals of 10^m.

The probable errors of the mean lengths in equations (1) and (2) are due to the errors of comparison only. The total probable errors of those mean lengths, when expressed in meters, depend, 1st, on the errors of comparison just mentioned; 2d, on the error in length of the 100^m comparator as measured with the iced bar; 3d, on the error in length of the iced bar when expressed in terms of the International meter.* The second and third errors when expressed as ratios may be taken as not greater than $\frac{1}{5000000}$ and $\frac{1}{4000000}$ part, respectively, or in 100^m, as not exceeding $\pm$ 0.020^{mm} and $\pm$ 0.025^{mm} respectively. These combined with the probable errors $\pm$ 0.023^{mm} and $\pm$ 0.022^{mm}, in equations (1) and (2), give $\pm$ 0.039^{mm} as the probable error of either tape expressed in meters at the mean of its observed temperatures on the 100^m comparator. For such extreme temperatures as 0° C. and 30° C., which are rarely reached in actual work, the probable errors rise to—

$\pm$ 0.057^{mm} and $\pm$ 0.052^{mm} respectively for tape No. 85, and
$\pm$ 0.060^{mm} and $\pm$ 0.057^{mm} respectively for tape No. 88.

The square root of the average of the squares of the probable errors of the tape lengths between 0° and 30°, supposing all such temperatures of equal frequency, is $\pm$ 0.045^{mm} for tape No. 85, $\pm$ 0.046^{mm} for tape No. 88. Hence it is concluded that for such temperatures as are likely to be had in the use of these tapes the probable errors of their absolute lengths will not exceed $\pm$ 0.05^{mm} or $\frac{1}{2000000}$ part of their lengths.

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* To these errors it may be essential to add the error of reference to the hydrogen scale of the mercurial thermometers used in determining the tape temperatures. It does not appear at present, however, that such error can appreciably increase the probable errors given in the text.

Results Obtained in the Measurement of St. Albans Base.

Explanation of Data.—In order to furnish a fairly complete idea of the precision attainable in the actual work of measuring a base, the results of the measures of St. Albans Base, 1892, will be given herewith. This base of 3 870.5^m was divided into four sections. The first three of these beginning at the west end were closely equal to 1 km. each. Five measures of this base were made. Four of them were made during the night time, when the temperature varied from 5° to 15° C. in the means for the several sections. The fifth measure was made during the day, in full sunshine, at a time when the temperature varied from 27° to 32° C. in the means for the different sections. The first two and the last measures were made with tape No. 88; the third and fourth measures were made with tape No. 85.

The wide range of temperature of these measures, and the use of two tapes whose equations differ, as shown above, by about 2.5^{mm}, would appear to afford a pretty good test of the efficiency of the apparatus and method.

Table No. 4, following, gives the results of these measures. The first column gives the date; the second, the time of day when the measure was made; the third, the direction in which the measure proceeded; the fourth, the mean temperature of the tape; the fifth, the temperature range, or the difference between the highest and lowest observed temperature of the thermometers; the sixth indicates by the letters R and F whether the temperature was rising or falling during the measure of a section, and the order of the letters indicates the order in which the changes occurred; the seventh gives the length of the sections in terms of the iced bar B_{17}, the excess over a round number of tape and bar lengths having been measured with a millimeter scale, and with a 15^m auxiliary steel tape in case of the fourth section; and the last column gives the number of the tape used.

TABLE No. 4.

Results of Measure of St. Albans Base.

West Base to Stake 10.

Date.	Time of Day.	Direction of Measure.	Mean Temperature.	Temperature Range.	Temperature Rising, *R*, Falling, *F*.	Value for Distance.	No. of Tape.
1892.	P. M.						
October 11...	7.20- 8.02	W. to E.	9.04° C.	3.40° C.	*F*	$200\,B_{17} + 258.2^{mm}$	88
12...	9.03- 9.44	E. to W.	7.62	2.70	*R*	244.5	88
13...	7.06- 7.40	W. to E.	13.30	3.00	*F*	252.6	85
13...	10.49-11.21	E. to W.	9.56	1.10	*R*	251.5	85
14...	2.53- 3.16	W. to E.	32.11	1.40	*R, F*	248.1	88
Stake 10 to Stake 20.							
October 11...	8.02- 8.44	W. to E.	5.92° C.	2.80° C.	*F, R*	$200\,B_{17} + 534.8^{mm}$	88
12...	9.44-10.25	E. to W	6.39	2.25	*F, R*	535.5	88
13...	7.40- 8.12	W. to E.	10.38	2.55	*F, R*	533 0	85
13...	11.21-11.53	E. to W.	9.05	0.80	*F, R, F*	536.0	85
14...	3.16- 3.49	W. to E.	30.47	0.80	*F, R*	536.0	88
Stake 20 to Stake 30.							
October 11...	8.44- 9.26	W. to E.	6.23° C.	1.50° C.	*R, F, R*	$200\,B_{17} + 527.0^{mm}$	88
12...	7.40- 8.22	E. to W.	7.84	1.60	*R, F*	524.0	88
13...	8.12- 8.44	W. to E.	9.92	1.10	*F, R, F*	527.8	85
13...	9.45-10.17	E. to W.	8.75	0.70	*R, F, R*	528.9	85
14...	3.49- 4.02	W. to E.	30.80	1.50	*R, F, R*	534.0	88
Stake 30 to East Base.							
October 11...	9.36-10.08	W. to E.	4.80° C.	0.75° C.	*F, R*	$172B_{17} + 9\,325.5^{mm}$	88
12...	8.22- 9.03	E. to W.	7 92	2.65	*F, R*	9 323.0	88
13...	8.44- 9.16	W. to E.	9.24	0.50	*F, R*	9 321.4	85
13...	10.17-10.49	E. to W.	8.57	1.00	*F, R, F*	9 328.6	85
14...	4.02- 4.26	W. to E.	27.46	0.95	*R, F, R*	9 333.0	88

Interpretation of Results.—Without entering into a minute discussion of these results, attention may be called especially to what is considered the key to their proper interpretation. In case there is any relative lagging of the tape and thermometric temperatures, it is obvious that the effect of such lagging will be more or less eliminated in the mean of two measures of a section made, the one under a rising and the other under a falling temperature. A similar elimination of the lag effect will occur in a single measure of a section if the temperature is rising for one half and falling for the other half, or *vice versa,* of the measure; and in general, the lag effect will tend to eliminate itself if the temperature fluctuates to any considerable extent about its mean trend.

These considerations seem to afford a satisfactory explanation of the ranges among the results of the measures of the several sections.

Thus, as might be expected from these considerations in connection with the data shown in the fifth and sixth columns of the above table, the range is greatest among the measures of the section from West Base to stake 10. The range is least in the measures of the section from stake 10 to stake 20. The middle portion of this latter section was on low, marshy ground compared with the ground at either end; so that, as indicated by the letters in the sixth column of the table, the temperature conditions were favorable to an elimination of the lag effect in every measure of the line.

Each section of the base was measured at night twice, once in each direction, by each of the two tapes. The conditions as to temperature, etc., differed little during the three nights when these measures were made ; *i. e.*, the sky was cloudless, or nearly so, there was little or no wind, and the measures were made while dew was condensing along most parts of the base line. Owing to these conditions, and the topographic conformation of the ground along the line, the temperature trend was in general reversed by the reversal of the direction in which the measures proceeded. For this reason we should expect the means of forward and backward measures of the sections to be largely free from the effect of lagging of the thermometers. This appears to be the case as shown by the following table, which gives the excesses in millimeters of those means for each section as measured by each of the two tapes :

TABLE No. 5.

MEANS OF FORWARD AND BACKWARD MEASURES OF THE SECTIONS.

No. Tape.	Section 1.	Section 2.	Section 3.	Section 4.	Whole Base.
88	+ 251.4^{mm}	+ 535.2^{mm}	+ 525.5^{mm}	+ 9 324.2^{mm}	10 636.3^{mm}
85	252.0	534.5	528.4	9 325.0	10 639.9

The accordance of these results leaves little to be desired ; but for the reasons already adduced, and for others given below, it is difficult to see how it can be otherwise than real.

Although the fact that means of forward and backward measures of a section indicated a marked elimination of some source of error was noticed in the measures of Holton Base in 1891, the explanation of that fact, presented above, did not occur to me until after the night measures

of St. Albans Base had been made. The full import of the explanation, indeed, was not appreciated until after the day measures of October 14th had been made; otherwise a reverse measure of the line would have been made on the latter day, though, as it happened, the temperature conditions were fairly favorable on that date for eliminating the lag effect.

In deriving the total length of the base, it is considered best to use the night measures only, since all our experience shows that the temperature uncertainty is least in such measures. Accordingly, the value adopted is—

$$772\,B_{17} + 10\,638.1^{mm}$$

or the mean of the four night measures.

If, on the other hand, we include the day measure and give it and each of the night measures the same weight, the result is—

$$772\,B_{17} + 10\,640.7^{mm}$$

which differs but 2.6^{mm} from the adopted value.

The results for the several measures of the whole base, in the order in which they were made, are—

$$\begin{array}{r} 772\,B_{17} + 10\,645.5^{mm} \\ 27.0 \\ 34.8 \\ 45.0 \\ 51.1 \end{array}$$

The range among these is 24.1^{mm}, or $\frac{1}{160000}$ part of the whole line. The range among the first four, or the night measures, is 18.5^{mm} or $\frac{1}{200000}$ part. The greatest divergence from the adopted mean is that of the last or day measure. The amount is 13^{mm}, or $\frac{1}{298000}$ part.

Probable Errors.—In computing probable errors from the above data we may proceed according to several hypotheses. Using 1 km. as the unit of distance to which such errors refer, we may assume (*a*) that all of the night and day measures of the several sections of the base are of equal weight, and that no elimination of systematic error results in the mean of a forward and backward measure; (*b*) that the night measures should be considered by themselves and treated as if they involved no errors due to lagging of the thermometers; (*c*) that the means of forward and backward measures of the sections as given in Table No. 5 are more or less free from errors due

to lagging, and that such means are alone competent to give an idea of the attainable precision.

The errors which result from each of these hypotheses will now be given. Let ε_a, ε_b, ε_c = the probable error of one measure of a kilometer according to the suppositions (*a*), (*b*), (*c*), respectively.

m = the total number of independently observed quantities, or total number of measures of the sections,
= 20 for supposition (*a*),
= 16 " " (*b*),
= 8 " " (*c*),

$[vv]$ = sum of squares of the discrepancies between the individual measures of the sections and their means, respectively.

Then from Tables Nos. 4 and 5 we find*

$[vv]$ = 250.57 for supposition (*a*),
= 142.94 " " (*b*),
= 4.80 " " (*c*).

According to the method of least squares, when we have m measures of equal weight of μ unknown quantities, the probable error of a single measure is expressed by—

$$\pm\ 0.6745 \sqrt{\frac{[vv]}{m-\mu}}$$

In the present case the number of unknown quantities, or $\mu = 4$, the number of sections of the base. Hence for the several suppositions we have $m - \mu = 16, 12, 4$, respectively. These data then give—

$$\varepsilon_a = \pm\, 2.67^{mm}$$
$$\varepsilon_b = \pm\, 2.33$$
$$\varepsilon_c = \pm\, 0.74$$

It may b served that if the mean values in Table No. 5, from which ε_c is derived, are not to a marked extent free from systematic error, as is assumed, we should have by the theory of errors—

$$\varepsilon_c = \tfrac{1}{2}\, \varepsilon_b \sqrt{2} = 0.71\ \varepsilon_b.$$

But the actual relation is $\varepsilon_c = 0.32\ \varepsilon_b$, or the ratio of the two errors is less than half as great as it should be if the hypothesis (*c*) were false.

It may be observed, also, that the work on the long comparator in determining the tape lengths affords an indirect means of estimating the precision attainable in the mean of two measures of a kilometer.

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* The sections are treated as of equal length, the modification arising from the fact that the section from Stake 30 to East base is 130^m short of a kilometer being unimportant.

As shown above, the probable error of a single determination of a tape length on that comparator is $\pm 0.20^{mm}$. This, as already explained, is almost wholly due to temperature uncertainty in the mean of six thermometer readings. If, now, we assume that the temperature uncertainty is on the average no greater in night work on a base line, and it does not appear to be so if the measures are made in a way to eliminate the lag effect, the probable error of a tape length from the mean of two in place of six thermometer readings should be $\pm 0.20^{mm}\sqrt{\frac{6}{2}} = \pm 0.20^{mm}\sqrt{3}$. With this for the probable error of a single tape length, the probable error of the sum of ten such lengths, or of one kilometer, is $\pm 0.20^{mm}\sqrt{30}$; and hence the probable error of the mean of two such measures is—

$$\pm 0.20^{mm}\sqrt{15} = \pm 0.77^{mm},$$

which does not differ materially from the value $\varepsilon_c = \pm 0.74^{mm}$ derived above. While no great importance is attached to this argument, since the results in Table No. 5 are too few to render such argument conclusive, it seems not out of place to note that the precision attained in this field work is not inconsistent with that attained in determining the tape lengths.

Lastly, it may be observed that the value of $\varepsilon_b = \pm 2.33^{mm}$, derived by using the night measures alone of St. Albans Base, is somewhat larger than the corresponding value which results from the measures of the sections of Holton Base made with the same tapes in 1891. Disregarding the measures of the two short sections (one of 100^m and one of 500^m) of this base, measures presenting abnormally small ranges, the 41 night measures of the remaining five sections, which vary in length from 900^m to $1\,200^m$, give for ε_b, or the probable error of one measure of a kilometer, $\pm 1.88^{mm}$. This smaller value is probably due partly to the smaller amount of lagging of the thermometers as fitted with the aluminum sheaths in 1891, and partly to the exceptionally favorable conditions of the standard kilometer of Holton Base for eliminating the lag effect. This section had about 200 meters at either end in open fields, while the intervening 600 meters were along a narrow lane cut through a dense forest. By reason of these conditions there was in general a marked change in temperature in passing from field to forest and *vice versa*, which change, as already explained, is favorable to the elimination of the lag effect in any single measure.

The 21 night measures of this kilometer taken by themselves show a probable error of $\pm 1.63^{mm}$ for one measure.

Now, as to the probable error, due to the errors of measurement just considered, in the whole length, or sum of the sections, of St. Albans Base, three values dependent on the three suppositions (*a*), (*b*), (*c*), respectively, may be derived. Thus, the probable error of the whole base is—

$$\varepsilon_a \sqrt{\frac{4}{5}} = \pm 2.39^{mm} \text{ according to supposition } (a),$$

$$\varepsilon_b \sqrt{\frac{4}{4}} = \pm 2.33 \quad \text{"} \quad \text{"} \quad (b),$$

$$\varepsilon_c \sqrt{\frac{4}{2}} = \pm 1.04 \quad \text{"} \quad \text{"} \quad (c).$$

Expressed as fractions of the base, these vary from the $\frac{1}{1620000}$ to the $\frac{1}{3720000}$ part.

The errors just discussed, or those developed in repeated measures of a line, appear to be the only ones of the compensating class which need be discussed. In comparison with these, the errors in grade corrections, in transfers to permanent marks, in the measurement of small fractions of tape lengths, etc., are trifling. It would seem safe to conclude, therefore, that the probable error of the adopted length of St. Albans Base, arising from all sources save that of error in the tape lengths, cannot exceed $\frac{1}{2000000}$ part.

With respect to the probable error of a tape length, the results of the determinations on the Holton comparator indicate that it cannot on the average exceed $\pm 0.05^{mm}$ as already explained. One circumstance, however, leads me to adopt a larger value. It is this: if we use the mean lengths of the sections of St. Albans Base given in Table No. 5, to compute a correction to the assumed difference in length of the tapes at 0° C., the mean value of such correction is found to be $+0.09^{mm} \pm 0.095^{mm}$, indicating that the difference in length of the tapes at 0° C. should be 2.54^{mm} instead of 2.45^{mm} as given by equations (3) and (4). Subseqently to the measurement of the base a series of comparisons of the tapes was made, mostly during the day and in sunshine, on a 100^{m} section of the base. These comparisons indicate a correction of the same amount with somewhat greater certainty. The amount of this discrepancy, it will be observed, is of about the same

magnitude as the probable error of the difference of the tape lengths derived from equations (1) and (2), viz.:

$$\sqrt{(0.057^{mm})^2 + (0.060^{mm})^2} = \pm 0.08^{mm},$$

so that no great weight can be attached to it. But inasmuch as the lengths of the tapes were determined by observing on their graduations with micrometer microscopes, while in applying them to measure a base a hand magnifier or the unaided eye is used, it is possible that some systematic error may have entered the measures of St. Albans Base. For this reason the extreme probable error of a tape length given on the 15th page of this paper, namely, $\pm 0.06^{mm}$, will be adopted in computing the probable error of this base. Combining this with the probable error from other sources of error, estimated above as not exceeding $\frac{1}{2000000}$ part, or $\pm 0.05^{mm}$ per tape length, we have for the total probable error of St. Albans Base—

$$\pm 3.02^{mm}, \text{ or } \frac{1}{1280000} \text{ part.}$$

The adopted length of the base as measured may then be written—

$$772\, B_{17} + 10\,638.1^{mm} \pm 3.0^{mm}.$$

To this must be applied a correction of -112.7^{mm} for grades, or slopes of the tape lengths, and a correction of -109.1^{mm} for an elevation of 180^{m} above sea level.

MATHEMATICAL APPENDIX.

Formulas Relative to Length of Tape.

Actual and Apparent Tension by Spring Balances.—If the spring balance used to give tension to the tape is adjusted to give correct tensions when in a vertical position, it will indicate (by its face readings) less than the actual tension when in a horizontal position. Such balances are liable also from wear and other causes to have an appreciable index correction.

To determine the actual tension in any case with such balances, let r be the index correction. It is the reading of the index when the balance is vertical, hook end down, and without load on the hook; it is *minus* when the index reads greater than zero, and *plus* when it reads less. Let R be the reading of the index when the balance is suspended by its hook, hook end up. Let W be the total weight of the balance found by weighing it on another balance. Then if T_1 denote the ob-

served or face reading of the balance when horizontal, and T denote the corresponding actual tension—

$$T = T_1 + r + \tfrac{1}{2}(W - R - r)$$
$$= T_1 + \tfrac{1}{2}(W - R + r).$$

Example.—On September 25th, 1891, the following values were observed with balance No. 53, U. S. C. & G. S., namely ·

$$\begin{aligned} r &= -\ \ 3.0 \text{ ozs.,} \\ R &= \ \ 35.0 \text{ ``} \\ W &= \ \ 49.2 \text{ ``} \\ T &= \ \ 25.0 \text{ ``} \end{aligned}$$

Hence—

$$T = 25 \text{ lbs.} + 5.6 \text{ ozs.}$$

Change in Length of Tape due to Change in Tension, Omission of One or More Supports, etc.—When the tension applied to a tape differs from the normal tension, or the tension under which the tape was standardized, a change in length of the tape results. Likewise a change in length will occur when the interval between equi-distant supports of the tape is changed, or when some of the supports are omitted. It is often convenient to omit one or more supports, as in crossing a road, a ravine, etc. Not infrequently, also, tapes are standardized by laying them on a flat or mural standard, and it thus becomes essential to know the shortening they undergo when supported at finite intervals instead of throughout their length. The following formulas apply to these cases:

Let—

w = the weight per unit length of the tape,

τ = the applied tension,

$a = \dfrac{w}{\tau}$

n = the number of sections into which the tape is divided by equi-distant supports,

l = the length of any such section,

L = the normal length of the tape, or the right line distance between its end marks when under standard tension,

$= \Sigma\, l = nl$, approximately,

μ = the reciprocal of the product of the modulus of elasticity of the tape by the area of its cross-section.

(1) Then the change in length, ΔL_1 say, in L due to a change $\Delta\tau$ in the tension is—

$$\Delta L_1 = n\, l\, \mu\, \Delta\tau + \tfrac{1}{12}\, a^2\, n\, l^3\, \frac{\Delta\tau}{\tau} \ldots\ldots\ldots\ldots\ldots \quad (1)$$

Example.—For tape No. 85, when supported at equi-distant intervals of 10^m we have—

$$\begin{aligned} n &= 10, \\ l &= 10^m, \\ w &= 22.32 \text{ grams per meter}, \\ \tau &= 25.5 \text{ lbs.} = 11\,566.66 \text{ grams}, \\ a^2 &= 372 \times 10^{-8}, \\ \mu &= 16 \times 10^{-9} \text{ for gram as unit*} \\ &= 450 \times 10^{-9} \text{ for ounce as unit.} \end{aligned}$$

Hence, for $\Delta\tau = 1$ oz.,

$$n\, l\, \mu\, \Delta\, \tau = 10 \times 10^m \times 450 \times 10^{-9} = 0.045^{mm},$$

$$\frac{1}{12}\, a^2\, n\, l^3\, \frac{\Delta\tau}{\tau} = \frac{1}{12} \times 372 \times 10^{-8} \times 10^7 \times \frac{1}{408} = 0.0076^{mm}.$$

$$\Delta L_1 = 0.0526^{mm}.$$

It may be observed that the quantity ΔL_1 can be measured directly by increasing and decreasing the tension in the vicinity of any assumed value of τ. The mean of several values determined in this way, with tape No. 85, is $\Delta L_1 = 0.053^{mm}$ per ounce when $\tau = 25.5$ lbs.

(2) Suppose a given tape to be divided by its equi-distant supports, 1st, into n_1 sections of length l_1; and 2d, into n_2 sections of length l_2. Then assuming the tension the same in both cases, if $n_2 > n_1$, the difference in distance between the end graduations of the tape, ΔL_2 say, in the two cases, will be expressed by—

$$\Delta L_2 = \Sigma\,(l_2 - l_1) = \frac{1}{24}\, a^2\, (n_1\, l_1^3 - n_2\, l_2^3) \ldots\ldots\ldots\ldots \quad (2)$$

Example.—For the 100^m tape No. 85, $n_1 = 5$ and $l_1 = 20^m$ when the supports are 20^m apart; and $n_2 = 10$ and $l_2 = 10^m$ when the supports are 10^m apart. Hence, in this case if $a^2 = 372 \times 10^{-8}$, as above—

$$\Delta L_2 = \frac{1}{24} \times 372 \times 10^{-8} \left(5\,(20)^3 - 10\,(10)^3\right) = 4.65^{mm}.$$

If a single support is omitted, we have only to make $n_2 = 2$, $n_1 = 1$, and $l_1 = 2\, l_2$ in equation (2). Thus the omission of a single support

* Since the cross-section of the tape is $6.34^{mm} \times 0.47^{mm}$, or 0.0298 sq. cm., the value of μ corresponds to a modulus of 2.1×10^6 kilos. per square centimeter, or 30×10^6 lbs. per square inch.

when $n_2 = 10$ and $l_2 = 10^m$, shortens tape No. 85 by 0.93^{mm}, supposing the normal tension to be 25.5 lbs. as above.

Similarly, the omission of m consecutive supports shortens a tape by—

$$\frac{1}{24} m (m + 1) (m + 2) a^2 l^3,$$

where l is the length of a section when no supports are omitted.

(3) When a tape is supported throughout its length, as when lying on a horizontal plane or on a mural standard, n_2 in formula (2) becomes infinite and l_2 infinitesimal. If we call the length of the tape in this case $L_0 = \Sigma l_2$, and omit the suffixes from n_1 and l_1, formula (2) gives—

$$L_0 - \Sigma l = \frac{1}{24} a^2 n l^3 = \Delta L_3, \text{ say} \quad \ldots\ldots\ldots\ldots (3)$$

This formula shows, for example, that tape No. 85 when supported at equi-distant intervals of 10^m, and when under a tension of 25.5 lbs., is shorter by 1.55^{mm} than it would be when under the same tension on a horizontal surface.

(4) Lastly, it will be of interest to have an expression for the change in length of a tape due to a change in its weight per unit length. Such a change may occur by reason of a deposit of dew on the tape or from wear of the same. Let Δw be the change per unit length, or the increment to w; and let the corresponding change in the total length of the tape be denoted by ΔL_4. Then, assuming as above that the number of sections of the tape is n, and that their lengths are each l approximately—

$$\Delta L_4 = -\frac{1}{12} n l^3 a^2 \frac{\Delta w}{w} \quad \ldots\ldots\ldots\ldots (4)$$

This formula shows, for example, that when tape No. 85 is supported at equi-distant intervals of 10^m and is under a tension of 25.5 lbs.; or when—

$$l = 10^m,$$
$$n = 10,$$
$$a^2 = 372 \times 10^{-8},$$
$$\Delta L_4 = -3.1^{mm} \times \frac{\Delta w}{w}.$$

Thus, in order to produce a change of $\frac{1}{1000000}$ part in the tape's length, or in order that ΔL_4 may be 0.1^{mm}, we must have $\Delta w = \frac{w}{31}$.

Formulas for Computation of Length of Measured Line.

Summation of Tape Lengths and Correction for Temperature.—The formulas of the preceding section give the actual length of the tape in

terms of its standard length, the index correction to the balance, etc. Such actual or working length may be most conveniently expressed in the form—

$$L = A + a + \alpha t,$$

wherein A is the nominal length of the tape, a round number of meters or feet; a is a small excess over that round number; α is the rate of expansion of the tape; and t is the tape's temperature in degrees C. Then the sum of N such lengths, t being supposed to vary from one length to another, will be—

$$\Sigma L = NA + Na + \alpha \Sigma t. \qquad (5)$$

The last term in this expression is the correction for temperature of the tape. As here given it assumes that the t's have been corrected for errors of the thermometers used. Generally, it suffices to apply an average correction to the observed values of t for several tape lengths, since the temperature does not often change much during the measurement of a section of a base.

Corrections for Set-Ups and Set-Backs and End Corrections.—These quantities, which are usually very small, are measured with a millimeter or other suitable scale. Their application in computing a measured length is obvious.

Correction for Grades.—The correction for grade is computed for each tape length, such length having a uniform slope from end to end. The difference in altitude of the ends of the tape, or the difference in altitude of the corresponding marking tables, is measured with an engineer's level. Call this difference h. The length of the tape being L, its horizontal projection will be—

$$\sqrt{L^2 - h^2};$$

and if we call the grade correction c,

$$c = L - \sqrt{L^2 - h^2}$$

$$= -\left(\frac{h^2}{2L} + \frac{h^4}{8L^3} + \dots\right) \qquad (6)$$

Usually the first term of this series suffices when a long tape is used. Thus, for a 100^m tape—

$$\frac{h^4}{8L^3} < 0.01^{mm} \text{ for } h < 2.9^m,$$

so that for such a tape, in all ordinary cases—

$$c \text{ in millimeters} = 5\ (h \text{ in meters})^2.$$

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TERRESTRIAL MAGNETISM IN NORTH AMERICA.

By CHARLES A. SCHOTT, Assistant U. S. Coast and Geodetic Survey.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

In this paper it is proposed to give, first, an historical outline from the time of Columbus to our own, showing the gradual accessions to our knowledge of terrestrial magnetism, with special reference to North America, to be followed by an exposition of, or reference to, the numerous laws so far recognized, with more or less certainty, as governing the changes in the direction and intensity of the earth's magnetic force within the specified region and period. This limitation is essential and will allow more space for the presentation of matter which may be of special interest to Americans.

The subject under consideration commends itself to our attention, both from a scientific and a practical point of view. The latter relation is obvious, since we have but to point to the latest evolution in engineers' activity, viz., electrical engineering. Of the former, it is

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

proposed here to give an account of the distribution of magnetism in its three elements—declination, dip and horizontal force—as well as of the continual changes, periodic or secular, to which they are subject. This subdivision is a matter of convenience for the analysis as well as for the instrumental measure of the magnetic force. The declinometer (or compass) determines the direction of the force in the horizontal plane; the inclinometer, or dip circle, the direction in a vertical plane of a freely suspended magnetic needle; and the magnetometer gives, in absolute measure, generally expressed in units of the C. G. S. system, the intensity of the force or of its horizontal component; hence, also, the vertical component and the total intensity.

Terrestrial magnetism considered as a science had no existence in the days of Columbus, and but little more could be gathered, in his time, of magnetic phenomena than the ancient knowledge of the attraction of the lodestone for iron and its directive force. The dual character of the magnetic property was apparent enough; that in the southwestern part of Europe the needle (north-seeking end) pointed slightly to the eastward was recognized, and it was believed that the declination at any place was invariable.

Not to refer to the current fable of a magnetic mountain in the north as the cause of attraction, even Galileo, at a much later period, thought that the fixed direction of the earth's axis might be due to magnetic attraction of a point in space.

Yet we owe to Columbus the discovery of a point in the agonic curve of the North Atlantic where, on September 13th, 1492, in latitude $+28^\circ\ 21'$ and in longitude $29^\circ\ 16'$ west from Greenwich, he noticed that the variation had changed from the east to the west side of the meridian. The declination remained westerly to the end of his voyage of discovery. He was closely followed by Sebastian Cabot (1497-98), who found, farther north and 110 miles west of Flores (Azores),* a second point of the same agonic. The declination along the Atlantic coast of North America, north of latitude 40° (about), has remained westerly to this day, though south of this parallel it has changed to *easterly*.

A century after Columbus, Dr. Gilbert† (styled the father of the

* C. & G. S. Bulletin, No. 6 (May, 1888).
† Appendix No. 19, C. & G. S., Report for 1880.

magnetic philosophy) published in 1600, his celebrated work, "De Magnete." He showed the earth to be a great magnet and elucidated most of the fundamental facts of magnetism. Thus we owe to him the terms "magnetic poles," "axis," "magnetic meridians," as well as "magnetic latitudes" (as measured by the dip or by changes in intensity).

The magnetic dip was unknown to Columbus, but was discovered by Hartmann in the year 1544*, though he was unable to measure it; so that the discovery is generally ascribed to Norman, in the year 1576, and was published in his work, "The New Attractive." Unlike declination observations which continued to be made, as of immediate necessity to the seaman, dip observations were only exceptionally noted until the last quarter of the eighteenth century, after which they become more numerous. A far more difficult problem to solve than that involving merely direction was how to measure the intensity of the magnetic force? The feebleness of the force in the earth's equatorial region as compared with its value in the polar regions, where it is more than double the equatorial value, was known to Gilbert (and it was first experimentally proved by Lamanon, from observations made in 1785–87); but it was not until the last quarter of the eighteenth century that even relative measures were practiced, though earlier attempts had been made to this end by counting the oscillations of the dipping needle (Graham, 1723), or of the horizontal needle (Mallet, 1769).

As was the case with the declination, the invariability of the intensity of the earth's magnetic force was at first believed in; but, when the contrary was recognized, the difficulty of comparing intensities at different places and at different times became apparent, not to mention the further complication of the needle gradually parting with its magnetism.

Humboldt, during his travels in tropical America in the years 1798–1803, noted the position of a point in the magnetic equator in Peru, and for some time intensities were expressed in terms of the intensity at that station. Several systems of measures, relative and absolute, were in use by different nations; but, at the present time, the C. G. S. system, proposed in 1881, has gained general acceptance. We may pass by here the several theories on terrestrial magnetism that were

*Dr. R. Wolf's Taschenbuch, Zurich, 1877.

advanced before the time of Gauss. In a memoir published by him in 1833, he showed how the magnetic intensity could be expressed in absolute measure, and in 1838 appeared Gauss' "Theory of Terrestrial Magnetism."* This theory is styled by the late Sir G. B. Airy "one of the most beautiful and the most important that has appeared for many years in physical mathematics."

In this treatise the general theory of terrestrial magnetism is developed independently of any particular hypothesis as to its nature and distribution, but the magnetic force at any place is supposed due to the collective action of all the magnetic particles of the earth's mass.

After developing the magnetic potential as a function of three variables in space, he determines its value for any point of the surface and develops the expressions for the three components of the magnetic force, whence for any place the declination, dip and intensity may be calculated. Magnetic data observed at but 12 points were employed, and the 24 coefficients needed to include magnitudes of the fourth order of development were calculated. The treatise is accompanied by a series of isomagnetic charts. Notwithstanding the paucity of observations, the irregularity of their distribution in space, and their want of simultaneity (the epoch being approximately 1830), this first attempt was a signal success. The reduction was repeated with better data in 1874 by Erman and Petersen; in 1881 by Icilius, and in 1885, with greatly extended material, by Dr. Neumayer. These authors confine themselves to the same order of terms as Gauss, and there seems to be no immediate need to include those of the fifth order (or 35 in all). What appears to be of more importance in a new attempt is the elimination of the local irregularities by excluding from the data all stations thus affected. Staff Commander Creak, R. N., pointed out some remarkable regions of disturbances; among these, the Bermuda Islands, likewise the Hawaiian group. But the greatest deviation of the needle due to local causes was recently discovered at a place off the east coast of Australia. It would seem that the magnetism in excess of the normal at these local foci is of the same character as that of the pole of the respective magnetic hemisphere.

Local disturbances were particularly studied and charted by Rücker and Thorpe in connection with their magnetic survey of the British

* For an English translation of it see Taylor's "Scientific Memoirs," Volume II. London, 1841.

Isles in 1886. In the United States, Kentucky apparently shows local deflections on a large scale, but these and a large number of smaller districts of disturbances remain yet to be developed or recognized. Gauss' theory as dependent on observations proves that there are but two magnetic poles on the globe, and there could not be any odd number. Halley's conception of four poles was announced at a time when but a few observations of the declination and inclination and none at all of the intensity had been made, and is obscured by confounding poles with foci of maximum intensity, the latter in the Northern hemisphere being two large regions, one (the stronger) west of Hudson Bay, the other in Central Siberia. These foci seem to be in some way related to regions of maximum cold.

Among the best known and comprehensive isomagnetic charts we mention Hanstein's isogonic charts for the epochs 1600, 1700 and 1800; Edm. Halley's "Tabula Nautica," anno 1700,* comprising mainly the Atlantic and Indian oceans. The Philosophical Transactions of the Royal Society, Vols. 158, 162, 165, and 167 (years 1868 to 1877) contain Sir Edward Sabine's great collection and isomagnetic charts (declination, dip and intensity) of observations embracing the earth's surface, the epoch being between 1840 and 1845. For modern charts showing the distribution of magnetism over the globe, the reader may consult the admirable series of charts for epoch 1885 in Berghaus' "Physical Atlas," 3d Ed., published in 1892, Art. Erdmagnetismus.

For the development of the theory of terrestrial magnetism, a knowledge of the position of the poles is of great moment; hence, direct observations in their vicinity, as far as accessible, are especially valuable, yet, notwithstanding the greater experience and less danger now in Arctic traveling than was the case half a century ago, the bold dash of Sir James Ross to the American pole on the shore of Boothia, in the spring of 1831, has not been repeated, and we are yet almost in total ignorance whether or not the pole holds a nearly fixed position or is subject to secular motion, to clear up which a magnetic expedition to this region would be highly desirable.† To accomplish this effectively science would now demand a complete magnetic survey of the region surrounding the pole.

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* Reproduced in the Greenwich Astronomical Observations for 1869.

† The reader desirous of further information on this matter may consult the article "An Expedition to the Northern Magnetic Pole," a discussion before the American Geographical Society, May 2d, 1892, in "Bulletin of the Society," Vol. XXIV, No. 2, June 30th, 1892.

The late explorer, Lieutenant Schwatka, thought he had evidence that in 1879–80 the position of the pole was to be found several degrees to the westward of the place where Ross had previously located it. To locate the position of the American focus of maximum total intensity is from the nature of the case impracticable, and local irregularities of distribution would defeat any attempt.

The discussion of the variations of magnetic force, especially at the observatories supplied with automatical (by photography) registering instruments, confirmed and extended our knowledge of the intimate connection of the changes of the needle with certain solar phenomena brought about probably by an inductive action of solar (electro-magnetic) radiation, as seen in the magnetic inequalities exhibited in the daily, annual and sun-spot cycles, as well as in solar rotation, and at times in irregular disturbances. Broun was the first to derive the synodic period of the solar rotation (about 26 days) from the magnetic observations at Makerstoun (1844–45); he was followed by Hornstein and other investigators who extended the research to the records of the several self-registering variation instruments.

Kreil, in 1841, and, independently, Broun, pointed out that a lunar irregularity could be traced in the magnetic records. Thus magnetism came to be regarded as a cosmical force influencing, probably by inductive interaction through the medium of the ether, the supposed magnetic condition of the larger as well as the subordinate bodies revolving about the sun. The analysis of the stream lines seen in the structure of the solar corona during eclipses led Professor Bigelow to the conclusion* that coronal poles do not lie at the extremity of its axis of rotation, and supposing a solar inductive action on terrestrial magnetism, the synodic revolution of the sun, about 26 days as deduced from the observed inequalities, might be accounted for by the periodic alternate presentation of the northern and southern solar pole towards the earth. Recently† A. Ricco has shown that the passage of large sun spots over the central meridian of the sun is generally followed by a terrestrial magnetic disturbance, the retardation being about 45½ hours.

We may now briefly refer to the sources whence our magnetic mate-

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* "American Journal of Science," Vol. XLII, July, 1891. See, also, his notes on a new method for the discussion of magnetic observations, U. S. Dept. of Agriculture; Weather Bureau Bulletin, No. 2, July, 1892.

† "Astronomy and Astro-Physics," January, 1893.

rial for North America is chiefly derived. The earlier records are necessarily from navigators and are restricted to declinations (variation of compass); it was only at a later period, when it became customary among maritime nations to send out exploring expeditions, that the elements of dip and intensity were added to the record. We have but space to mention a few leading names. For the East Coast, the Gulf and West Indies: Hudson in his third voyage, 1609, skirted the Atlantic coast from Maine to North Carolina, Champlain (1604–12) coasted between Nova Scotia and Cape Cod, and, later, Bayfield, Orlebar, Barnett, Home, Milne and many others. For the Pacific Coast and Alaska: Drake (1579 on the coast of New Albion, now California), Bering (1727–29 in Alaskan waters), Cook (1768–80), La Perouse, Malaspina, Vancouver (1790–95), Kotzebue, Beechy, Lütke, Erman (1828–30), Belcher, Wilkes (1841), Maguire (1852–54) and Lieutenant P. H. Ray (1881–83), both at Point Barrow.

For the Arctic Region of North America we meet with Baffin (1616), James and John Ross (1818), Parry (1820–25), Franklin, Dr. Kane (1853–55), Dr. Hayes (1860–61), Hall (1871), Nares and Markham (1875–76), Lieutenant A. W. Greely (1881–84) and other explorers.

There were five stations located in North America by the representatives of several nations taking part in the International Polar Research of 1882–83; they were Fort Conger, Arctic America, in charge of Lieutenant Greely; Fort Uglaamie, Point Barrow, Alaska, in charge of Lieutenant Ray (United States); Kingua Fjord, Labrador (German); Godthaale, Greenland (Danish), and Fort Rae, British Possessions (English). At these stations an enormous number of observations was accumulated and still awaits further discussion.

Of land expeditions, that of Lieutenant Lefroy in Canada and the Hudson Bay Company's Territory was, perhaps, the most extensive.* Thomas Simpson and Lieutenant Younghusband also made many observations in the British Possessions. In the United States we have to mention the expedition of Major Long, U. S. A. (1819), the exploration tours of Prof. Nicollet (1832–36), Dr. Locke (1838–43), Prof. Loomis (1838–41)†, Dr. Bache, Friesach (1856–57), and other names. The observations made by army officers in charge of the geographical surveys west of the 100th meridian are very numerous, as are also the observa-

* Diary of a Magnetic Survey, etc., during 1842–44. London, 1883.

† For his extensive collection of observations, see "Sill. Jour." Vol. XXXIV, 1838, and Vol. XXXIX, 1840.

tions due to the U. S. Lake Survey, the U. S. Coast and Geodetic Survey, and the surveys of the Public Lands; further, we have the results from the surveys of International boundaries as well as interstate boundaries and the publication of the State surveys in charge of geologists; as, New York (Regents' Reports), Pennsylvania, New Jersey*; perhaps the most complete magnetic survey of a State is that of Missouri, by Prof. F. E. Nipher, of Washington University, St. Louis (1878–82); also, the magnetic surveys made under the direction of the National Academy of Sciences, 1871–76; and a great variety of other sources, notably those published by societies, associations, or from records or deeds, books of travels, historical works, and lastly from surveyors in general. Respecting the manner of conducting magnetic surveys there are two ways of proceeding, first, one or more parties to accomplish the work proposed in a period of a few years; this will answer for a small area and should be repeated at intervals of, say, a quarter of a century, in order to ascertain the secular changes (as an illustration we possess three magnetic surveys of Great Britain); or, secondly, in the case of an extended territory, as, for instance, that of the United States, observations made at any time within the area are collected and reduced to any desired common epoch by means of the known secular change; this demands a close study of the secular variations to be had only from extended records at certain selected stations. This last course has been pursued by the U. S. Coast and Geodetic Survey for the purpose of supplying its charts with the declination for the epoch of publication, together with the annual change.

Returns have been made from the following magnetic observatories (with dates added when founded and discontinued):

1. Philadelphia, Girard Coll., Pa. 1840–45
2. Toronto, Canada 1840–93
3. Sitka, Japonski Island, Alaska 1842–67
4. Key West, Florida 1860–66
5. Habana, Colegio de Belen 1863–93
6. Madison, Wisconsin 1878–81
7. Mexico, Observatorio Central 1879–93
8. Los Angeles, California 1882–89
9. Washington, D. C., U. S. Naval Observatory. . 1888–93
10. San Antonio (two stations), Texas 1890–93

* Prof. G. H. Cook, Trenton, 1888.

The results collected by the U. S. C. and G. Survey number several thousands; of these, 1 245 declinations were discussed for secular variation (see Appendix No. 7, C. and G. Survey Report for 1888, 7th Edition), and the results at 3 237 stations will be found discussed and chartered (isogonics) with respect to distribution in Appendix No. 11, Report of 1889; the dips (about 2 000) and intensities (about 1 500) are given and discussed in Appendix No. 6, Report for 1885, accompanied by isoclinic and isodynamic charts. We shall devote the small space remaining to the exposition of some of the laws of variation and distribution of the magnetic force within our geographical limits possessing special general interest.

It is a matter of common observation that a magnet, when light and delicately suspended, is seldom or never at rest, but is continually shifting its direction. This motion consists of oscillations of various periods, of tremors and occasionally of outbursts of violent and irregular changes due to the so-called magnetic storms; the variations in intensity are of the same character.

The variations from the normal values are studied by means of differential instruments, those of the intensity demanding two, viz.: one for the horizontal component, the other for the vertical component; hence, any laws to which these are subject have their counterparts in the dip and total intensity.* In general, declinations and intensities are subject to the same periodic and non-periodic fluctuations, and hence, give rise to similar laws.

Beginning with the solar diurnal variation, its phase depends on local time and its character is but slightly affected by geographical position, except in the higher magnetic latitudes. About sunrise the north end of the horizontal needle is generally found approaching to or near its most easterly deviation from the magnetic meridian. This extreme is reached at 8 o'clock A. M. (about), the deflection being about $3\frac{1}{4}'$. The north end of the needle then turns to the westward and reaches the second or westernmost extreme a little before $1\frac{1}{4}$ o'clock P. M., the deflection being about $3\frac{1}{2}'$; hence, total diurnal range, $6\frac{3}{4}'$. The return motion is during summer slightly interrupted by a small retarding wave during the night. The normal value of the declination is reached at $10\frac{1}{2}$ o'clock A. M., very nearly, shifting

* These relations are $\delta\,\Theta = \sin.\,\Theta\cos.\,\Theta\left(\frac{\delta V}{V} - \frac{\delta H}{H}\right)$ and $\frac{\delta F}{F} = \cos.^2\Theta\,\frac{\delta H}{H} + \sin.^2\Theta\,\frac{\delta V}{V}$

from about 10 o'clock A. M. in summer and to 11½ o'clock A. M. in winter; the times of elongation and the hourly values are likewise subject to an annual inequality; also the range which in January is a minimum and in August a maximum, when it is double the former value. There are but few days in the year when this diurnal variation is not noticeable or it may be obscured by irregular motions, and these happen generally in the winter season.

The annual variation of the declination consists of a small inequality with a range of about one minute of arc. The diurnal variation is also subject to a long period inequality, *i. e.*, the sun-spot cycle of about 11 years, the observed diurnal range being smallest in years of minimum spot activity and largest in years of maximum activity, with a gradual change from one epoch to the other, the ratio being about 1 to 1½.

The variation depending on the solar rotation is small in the lower latitudes; thus at Los Angeles, Cal., it is but 2¼″ either way from the normal direction, but it becomes large for stations near the magnetic pole. The resulting synodic period is about 26 days.

The lunar inequalities exhibited in the declination are likewise of small amplitude, but have the peculiarity of producing, similar to tidal action, two maxima and two minima in each lunar day (about 25 solar hours), but there is no reflex action perceptible in any way related to the sun-spot cycle. The angular deflection (half range) is about 10″ varying between 5″ and 20″ at different stations. There is an annual inequality in the lunar diurnal variation, both in times of phase and in range, depending on the seasons when the sun is north and when south of the equator. Further, there is an effect on the declination which depends on the moon's place in its orbit and relative to the sun which is as yet not satisfactorily demonstrated.

The declination change due to the varying phases of the moon has also been studied, the range between full and new moon being about 9″; the change due to the variations in the moon's declination amounts to about the same value, but the parallactic inequality ranges only 2″ between apogee and perigee.*

Of great importance to the physicist, as well as to the surveyor, is the secular variation of the declination; it is probably of periodic character, but composed of many subperiods, and is, hence, of great complexity, which renders any predictions of more than a few years ahead a

* See, for instance, Appendix No. 9, Report for 1890.

rather hazardous matter. In our complete ignorance of its cause, its laws, so far as they have become apparent, could only be derived from a tentative study of the records extending over long periods or centuries. Appendix No. 7, C. & G. S., Report for 1881 (of 312 4to pp.), is specially devoted to this subject. Thus far it was found sufficient to express the law of change of the declination by a periodic function with one or more terms of periodicity, so that in the most simple case four unknown quantities had to be determined from the observations by the method of least squares, namely, the normal value and the length, parameter and phase of the wave. The periods demanded by the observations range from about 250 years to about 350 years according to geographical position, but outside our geographical limits the range is more than double the smallest given above (which holds for our Atlantic coast stations).

The amplitude of the secular swing varies from a few degrees to an, as yet, unknown amount. The motion of the phase is very curious; thus, we find the years of the last occurrence of the stationary phase of extreme minimum west elongation (or of its extreme maximum east declination), as follows:

At	Halifax, N. S.	about	1714
"	Eastport, Me.	"	1753
"	Boston, Mass.	"	1780
"	Philadelphia, Pa.	"	1802
"	St. Louis, Mo.	"	1822
"	Salt Lake, Utah.	"	1873
"	San Francisco, Cal.	"	1893

The secular variation wave thus swept across the country from east to west, but apparently it took a century to do this. How far this movement will continue it is impossible to say.

More complicated than the variations noted above are the so-called disturbances. These have, so far, only been treated successfully by the statistical method; but their very separation from the general mass of observations is a matter of difficulty about which opinions differ. The best method yet devised, in the writer's opinion and one followed by him, is that of Lloyd and Sabine. Disturbances may occur at any time; they cannot be predicted; they are sudden, with rapid and great fluctuations, amounting sometimes to several degrees of deflection

they have been observed in connection with luminous outbreaks on the solar surface; they often take place over large parts or even over the whole surface of the globe simultaneously; they may last a few hours or may continue even for three or more days; they are often accompanied by auroral lights and by strong earth currents. When analyzed, they exhibit a solar diurnal variation, the westerly and the easterly disturbances, however, following different laws. They have also an annual variation and seem to depend largely on the sun-spot cycle; they exhibit themselves more conspicuously at certain hours of the day. But space forbids to follow up these minutiæ, and we shall have to content ourselves with the statement that laws in all respects similar to those mentioned above for the declination hold good also for the horizontal and the vertical components of the magnetic force.

The variations of intensity, however, do not obtrude themselves on the attention of the surveyor; it is only at laboratories or in special investigation (scientific research) that they must be taken into account.

If this brief outline of a branch of terrestrial physics should prove to be the means of directing renewed attention to it, the preparation of this article would be well repaid.

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FUNDAMENTAL UNITS OF MEASURE.

By T. C. MENDENHALL, Superintendent of the U. S. Coast and Geodetic Survey.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Engineering is the art of construction; but to limit it to this would be to restrict its meaning much within the range of the ordinary use of the word. In a broader sense, engineering includes all operations whose object is the utilization of the forces of Nature in the interests of man. It is both an art and a science, and as a science it consists for the most part of mathematics applied to physics and mechanics. It is of necessity, therefore, a measuring science, and a congress of engineers ought, in the nature of things, to be interested in anything relating to progress in metrology.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Fortunately the literature of this subject is neither scanty nor difficult of access. Much attention has been given to it in all parts of the world during the last half of this century, and in the United States especially numerous and valuable papers and reports upon the subject of weights and measures have appeared during this period. Indeed, it would be difficult, if not impossible, to contribute to either the historical or the controversial aspect of the question anything new and of notable value.

In spite of an extensive and widely circulated literature, however, it is very distinctly in evidence that the origin and genesis of the units of measure in customary use in the United States and among most English-speaking people, and their relation or want of relation to each other, are matters concerning which many engineers are not well informed.

Perhaps not a large majority of members of the profession in good standing would be able to answer accurately the question, What is a yard? or What is a pound? In view of this fact, no excuse need be offered for presenting a statement of facts relating to fundamental standards in this country at the present time, and for the sake of clearness this statement will be prefaced by a brief consideration of the principles involved in the evolution and selection of standards, together with a *résumé* of genealogical history, showing their origin and ancestry. Of the latter little detail will be given, as the extensive and easily accessible literature upon the subject renders it unnecessary.

The measure of a magnitude is its numerical evaluation. In a direct way this is accomplished by ascertaining how many times it contains another magnitude of the same kind or nature, which is adopted as a unit. Thus a length is selected as a unit for the measurement of length, a volume for the measurement of volume, a time for time measurement, and so on. At first it seems that this condition of sameness of the unit and the thing measured is a necessity. A little reflection will show, however, that it is open to the objection that it naturally, although perhaps not necessarily, leads to an almost indefinite multiplication of independent units. The discovery and development of inter-relations among measurable magnitudes, which has gone on from the earliest times, has tended towards a reduction in the number of units and, consequently, to a great simplification of the

whole subject of metrology. So simple and evident a device as relating the unit of volume to the unit of length has only been satisfactorily realized in comparatively modern times; and, with a single exception, it may be affirmed that units of volume now in use were originally in no way related to units of length, most of them being of accidental and now unknown origin.

That a legal bushel in the United States must contain 2150.42 cu. ins. is convincing evidence that the foot or the yard has no place in its ancestry, and although there is a plausible explanation of the fact that a gallon contains 231 cu. ins., it points only to a modified volume and not a selected one.

Many interesting illustrations of the great advantage gained by neglecting the principle that "like measures like" might be given, and one or two will, perhaps, be found instructive. In observing that property of matter known as "conductivity," either as to heat or electricity, qualitative or relative conclusions were for a long time all that was required. It was at first sufficient to say and to know that one substance conducted heat or electricity better or worse than another, but with the advance of knowledge of physics it became desirable and often necessary to give numerical expression to these relations. In such cases as this the practice has usually been to select some particular substance which possesses the property in question in a higher or in a lower degree than any other and adopt it as a standard. Thus barely a quarter of a century ago conductivities of different bodies for heat or electricity were expressed in terms of copper or silver; a lampblack surface was the standard for radiation or absorption and in most instances the standard was arbitrarily rated at 100. The literature of science contains many examples of elaborate and otherwise valuable investigations which are rendered quite worthless by the uncertain and unscientific units of measure employed. An example of the persistent use of this principle is to be found in the still common mode of expressing the density of matter, by referring it to the density of a certain kind of matter, namely water, the numerical representation of the ratio being known as "specific gravity." It has taken some years for even scientific men to fully appreciate the objectionable features of this sort of metrology, because it has required some time to prove beyond doubt that all kinds of copper or silver do not conduct alike, nor do all samples of lampblack radiate alike; and also that the con-

ditions under which the density of water is constant are difficult of realization.

Another factor which has been, up to a very recent time, of first importance in the selection of standards, is the tendency to seek in Nature something of constant dimensions or invariable mass which possesses that general availability essential to adoption as standard. The nomenclature of metrology bears testimony to this. In our own customary system of weights and measures, the occurrence of such units as the foot, hand, grain, ell, etc., tells of the frequent recourse to natural units. This is not alone characteristic of earlier and ruder systems, but in modern metrology we have recorded the efforts of scientific men to realize this theoretically desirable condition in the selection of the quadrant of the earth, the length of a seconds pendulum and the wave length of a particular kind of light for linear standards. The only natural standard which up to this time can be said to have satisfied the requirements is the unit of time, which is the sidereal day. This might itself be considered a derived rather than a fundamental unit, and, indeed, it is difficult to conceive of any time unit other than one based on motion. The motion of the earth is assumed to be a uniform rotatory motion, and the unit is the duration of a single revolution. Vibratory or periodic motion seems to offer many advantages as a time standard, and various forms have been suggested from time to time. It has been shown that the period of a freely suspended invariable pendulum furnishes in practice a more uniform and constant time unit than the best clocks or chronometers. All standards of this type depend on the persistence of gravity, however, and of this we cannot be assured. The prime requisites of a standard are constancy and universal availability, and as the present time unit, the sidereal day, possesses these in a high degree, it is not likely that it will soon be supplanted. It would be extremely desirable, however, if a unit of time could be devised which would survive such terrestrial or celestial disturbances as would materially alter the revolution of the earth upon its axis. Something of this kind is necessary if time observations made during the present cycle are to be available in future ages, and it is possible that the determination of the relation of the wave length of light to the generally accepted unit of length may indirectly furnish a time unit possessing this characteristic in a high degree.

The greatest advance in the science of metrology in modern times

is essentially due to Gauss, and it consists of the so-called "absolute" system of measurement. Quite as much as to the author of this ingenious system metrologists are indebted to the celebrated British Association Committee on Units, led by Lord Kelvin, and including such men as Clerk Maxwell, Foster, Stoney, Fleeming Jenkin, Siemens, Bramwell, Adams, Balfour Stewart and Everett. Evincing a freedom from national prejudices worthy of the distinguished body which they represented, this committee placed the system of Gauss upon a firm and enduring basis by deriving its fundamental units from the only system of weights and measures, which, starting from a scientific basis and constructed upon scientific principles, has ever found favor among a considerable number of people, and which has now become well-nigh universal.

The tendency of the absolute system is towards simplicity through a reduction of the number of fundamental units to a minimum, while at the same time it affords every facility for the multiplication of derived units to meet the demands of convenience in practice. But however complex and numerous these derived units may be, they all grow out of the same elements, and are, therefore, easy of comparison and interchange.

It is not too much to say, and it is important that it should be said, that the beauty, simplicity and convenience of this system are not yet fully understood and appreciated by many engineers who might be greatly benefited by its use. As a single illustration, reference may be made to the still very general use of the foot-pound as a unit of work and energy. Let no one imagine that the objection to this unit lies in the fact that units of the metric system are not used, for kilogram-meter, which is also very common, is equally objectionable. The difficulty rests in the introduction of a variable, and in this instance unnecessary, magnitude; namely, the force of gravitation. If the fundamental units, foot, pound and second, be used, we have a unit of work sometimes called the "foot-poundal," and if the centimeter, gram, second, system be used, we have the well-known "erg." These units are vastly more convenient in practical use than their gravitation relatives, besides being invariable, whenever and wherever the units of length, mass and time are invariable.

Modern scientific metrology may be said to rest upon a few simple principles which may be summarized as follows :

The number of independent fundamental units should be minimum. In general not more than three are required.

They should be such as admit of a ready and accurate comparison with other magnitudes of the same kind. Units of length, mass and time satisfy this requirement better than any other that can be selected.

They should be capable of use for such comparisons at places and times widely separated; hence they ought to be comparatively easy of reproduction and transportation and, as far as human ingenuity can secure, invariable in their magnitude. Units of length, mass and time satisfy these conditions better than any other.

They should also be so related to each other, as far as such relation is possible, and the multiples and submultiples should be so related to them that units of every possible dimension and character for convenience in the measurement of all measurable things may be derived from them in the simplest manner, and thus be capable of the easiest reduction and interchange. The units of length, mass and time, as represented by the centimeter, the gram and the second, fulfill these requirements almost as perfectly as possible. The second falls short of the others because its multiples are not decimally derived, but its use is and has long been so nearly universal that it is not likely to be modified in that respect in the near future. Indeed, a decimal system as applied to time is much less important than when considered in relation to length and mass.

As to the constancy of these units, an arbitrary length and an arbitrary mass are much more capable of accurate reproduction than any natural units of which we now know. When reproduced in considerable numbers and of the best known material, and when widely distributed throughout the civilized world as they now are, under the direction of the International Bureau of Weights and Measures, anything like destruction or loss of the standards must be regarded as well-nigh impossible. Copied in materials of various kinds and preserved under conditions widely varying, it is hardly likely that any secular change in the standards can escape detection, and the accurate determination of the meter in light waves now in progress will afford a valuable check on the constancy of the standard of length.

It thus appears that the metric system with its derived units is to-day by far the most perfect system of metrology ever used by man, and that it lacks little of theoretical perfection. It can hardly be

denied that in one or two matters of minor importance it is susceptible of improvement, but it possesses the inestimable and unapproachable advantage of being actually in use by the great majority of civilized nations. Among the innumerable metrological schemes which have made their appearance within the past 100 years, it is quite possible that some one of them possesses advantages over that based on the meter and the kilogram, and that it would be preferred if we were starting afresh with the whole question. But we are not starting afresh, and it is certainly a cause for sincere and earnest congratulation that a system which is so rapidly advancing in public favor is as nearly absolutely perfect as is this.

Let us turn now to a brief consideration of the origin and present condition of what Lord Kelvin has justly characterized as the brain-wearying, intellect-destroying system of weights and measures in use among English-speaking people.

The fundamental unit of length is the yard, and the unit of mass is the pound. In the time of Edward II it was enacted (A.D. 1324) that three barleycorns, round and dry, should make 1 in. and 12 ins. make 1 ft. The earliest actual material standard yard, of which there is reliable account, dates back to the time of Henry VII (about A.D. 1490). In the *Transactions* of the Royal Society it is recorded that in 1742 "some curious gentlemen, both of the Royal Society of London and of the Royal Academy of Sciences at Paris, thinking it might be of good use for the better comparing together the success of experiments made in England and in France, proposed some time since that accurate standards of the measures and weights of both nations, carefully examined and made to agree with other, might be laid up and preserved in the archives both of the Royal Society here and of the Royal Academy of Sciences at Paris," and determined to bring about an exchange of copies of the standards of weight and mass of the respective countries. This led to an examination of the original standards of the Exchequer and their copies. It was found that the standard yard then in use was a square rod of brass, of breadth and thickness of about ½ in. The ends were neither exactly flat nor parallel. The standard was an end-measure and a matrix was provided for it. Near each end of the yard was stamped a crowned E and it dated from about 1588. Considered as a standard, its character was very inferior, but less so than the old standard of King Henry VII, which was examined

at the same time. This is described as an "old eight-sided rod of brass, of the thickness of about ½ in., very coarsely made, and as rudely divided into 3 ft., and one of these feet into inches." This is the standard which dates from A.D. 1490, and is the earliest known material yard.

In 1758, under instruction from a committee appointed by Parliament, John Bird constructed copies of the then existing standards (Elizabethan), one of which, a line measure, was recommended for adoption as the legal standard of length. A copy of this was made by the same artist in 1760, and is known as Bird's standard of 1760, to distinguish it from his first copies made in 1758. Although the subject received much consideration during the next half century, it was not until 1824 that any action was actually taken by Parliament. It follows that up to this date the legal standard of length in Great Britain and her colonies continued to be the very imperfect standard of Elizabeth referred to above. In 1824, however, it was finally enacted that Bird's standard of 1760 should be the fundamental unit of length, and in the same act it was provided that in case of loss it should be reproduced by means of its supposed known ratio to the length of a seconds pendulum at London. In 1834 the Parliament Houses, in one of which this standard had been preserved, were destroyed by fire. It is interesting to note that the conflagration was due to the burning of the "tallies" or sticks on which accounts had been kept by means of notches, and in the use of which the Government officials had persisted for many years after it had almost become a lost art elsewhere, thus exhibiting a conservatism characteristic of the whole course of the English Government in reference to metrology and allied sciences.

The legal standard having been destroyed in this manner, it was found impracticable to reproduce it, as had been intended, by the use of a pendulum, and accordingly a new standard was prepared under the direction of Mr. Sheepshanks from a half-dozen excellent copies of the destroyed standard which were available. This was legalized by an Act of Parliament in 1855, and is the Imperial standard yard of Great Britain to-day. It is a line measure, made of bronze, the total length being 38 ins. and the cross-section 1 in. square. At the time it was prepared several copies were produced, one of which, known as Bronze No. 11, is in the United States Office of Weights and Measures at Washington.

To recur now to standards of length in the United States, it is necessary to repeat the often-published statement that although the Constitution authorizes Congress to establish a system of weights and measures, it has never exercised this authority except in the matter of legalizing the metric system in 1866. The weights and measures in use in the Colonies before the Revolution were almost entirely those of Great Britain, and they continued in use without special legalization for a long time after independence was declared. The first Superintendent of the Coast and Geodetic Survey, Mr. Hassler, requiring an accurate standard of length in the operations of that Bureau, obtained from Troughton, of London, in 1814, a brass bar about 82 ins. long, 2.5 ins. wide and ½ in. thick. This bar was a direct descendant of the Bird standard of 1760, a number of copies of which had been made by Troughton.

It being necessary for the Executive Departments of the Government to have some standards of weight and measure properly authenticated, for the purpose of levying taxes, duties, etc., this bar, or rather one particular yard of it, from the 27th to the 63d inch, was adopted as the standard of length. It was supposed to be precisely equal to the British standard at a temperature of 62° Fahr. A direct comparison with the copies of the new Imperial yard of 1855, however, showed that it was too long at that temperature, and this fact gave rise to the idea which found its way into scientific literature that the English and American yards were different, the latter being the longer. The action taken in the Office of Weights and Measures was simply to change the temperature at which it was a standard, so as to bring it into agreement with the English yard. As a matter of fact its use as a standard was practically discontinued, and the bronze copy of the Imperial yard was accepted in its place, together with another copy of this yard made of Low Moor iron and so designated.

It will thus be seen that, as far as the Government is concerned, we have followed the English in the matter of standards of length, and their yard and ours have always been as nearly as practicable identical.

The same is essentially true in regard to the standard of mass. There is an important difference, however, in that Congress did, in 1828, legalize a standard Troy pound for purposes of coinage. This was a copy of the British Troy pound of 1758, which in 1825 became

the Imperial standard. It is preserved in the Mint at Philadelphia, and is known as the Mint pound. The standard avoirdupois pound of the Treasury Department was derived from this Troy pound. Both are very inferior in construction and unsuitable for standards. The present Imperial standard of mass of Great Britain is a platinum avoirdupois pound. It was derived from a copy of the standard referred to above, which was lost in the burning of the Parliament Houses. As the Imperial standard and our own have thus a common ancestor, it is assumed that they are the same.

Besides these units of length and mass the executive officers of the Government adopted two units of volume, the gallon which contains 231 cu. ins. and the bushel of 2 150.42 cu. ins. They are old English measures and differ very materially from the imperial gallon and bushel now in use in Great Britain.

The above statements apply to what may be known as National or United States standards only in the limited sense that they are the standards of the executive branch of the Government. The whole subject of standards, with the exeception as to the metric system already noted was, in the absence of definite action by Congress, left to the law-making authorities of the several States. In view of the great and intelligent interests in this subject exhibited by Washington, Jefferson, Adams, Gallatin and others of the early statesmen, the omission to legislate in Congress must be attributed largely to the fact of great dissatisfaction with the present system and a hesitancy to recommend any other, however perfect it might seem to be, until it had received the test of actual trial. Realizing the danger which was impending of inharmonious and unscientific legislation by the several States, Congress decided in 1836 to encourage uniformity throughout the country by the distribution among the various State Governments of complete sets of weights and measures copied from the standards adopted in the United States Office of Weights and Measures. Some States had already legalized standards differing somewhat from these, but they were soon accepted by all, thus establishing a practically uniform system throughout the country and one in agreement with that adopted by the Government. Strictly speaking, however, each State has its own standards, and they are entirely independent of, although copied from, those in use at Washington. But, as has already been explained, the latter have not themselves been regarded as fund-

amental standards, being only copies of the Imperial standards of Great Britain, in the case of the yard, or descended from the same ancestry, as in the case of the pound, and assumed to be the same. It thus appears that practically, and until a very recent period, our whole system of length and mass measurement was made to depend upon the Imperial yard and pound of Great Britain.

The most important legislation upon this subject from the founding of the Government to the present time is the Act of Congress of July 28th, 1866, legalizing the metric system of weights and measures throughout the United States. It has not been generally recognized that this system is and has been for more than a quarter of a century the only system whose use is made legal throughout the whole country by Act of Congress. Since the passage of this Act there has been a decided advance in the use of this system among all civilized nations. This remarkable movement, in which the United States Government, through annual contributions of money and diplomatic negotiations, has had a large part, leaves no room for doubt that in the comparatively near future all mankind will be in the fullest enjoyment of the great boon of a single, universal system of weights and measures, and one as nearly perfect in form and design as could well be expected.

The recognition of this fact has led to recent action on the part of the Office of Weights and Measures at Washington, which is of such importance as to justify the repetition here of the words of Bulletin No. 26, United States Coast and Geodetic Survey, April 5th, 1893, in which it was first announced.

Fundamental Standards of Length and Mass.

"While the Constitution of the United States authorizes Congress to 'fix the standard of weights and measures,' this power has never been definitely exercised, and but little legislation has been enacted upon the subject. Washington regarded the matter of sufficient importance to justify a special reference to it in his first annual message to Congress (January, 1790), and Jefferson, while Secretary of State, prepared a report at the request of the House of Representatives, in which he proposed (July, 1790) 'to reduce every branch to the decimal ratio already established for coins, and thus bring the calculation of the principal affairs of life within the arithmetic of every man who can multiply and divide.' The consideration of the subject being again urged by Washington, a committee of Congress reported in favor of Jefferson's plan, but no legislation followed. In the meantime the executive branch of the Government found it

necessary to procure standards for use in the collection of revenue and other operations in which weights and measures were required, and the Troughton 82-in. brass scale was obtained for the Coast and Geodetic Survey in 1814; a platinum kilogram and meter, by Gallatin, in 1821; and a Troy pound from London in 1827, also by Gallatin. In 1828 the latter was, by act of Congress, made the standard of mass for the Mint of the United States, and, although totally unfit for such purpose, it has since remained the standard for coinage purposes.

"In 1830 the Secretary of the Treasury was directed to cause a comparison to be made of the standards of weight and measure used at the principal custom-houses, as a result of which large discrepancies were disclosed in the weights and measures in use. The Treasury Department being obliged to execute the constitutional provision that all duties, imposts and excises shall be uniform throughout the United States, adopted the Troughton scale as the standard of length; the avoirdupois pound to be derived from the Troy pound of the Mint, as the unit of mass. At the same time the Department adopted the wine gallon of 231 cu. ins. for liquid measure and the Winchester bushel of 2150.42 cu. ins. for dry measure. In 1836 the Secretary of the Treasury was authorized to cause a complete set of all weights and measures adopted as standards by the Department for the use of custom-houses and for other purposes, to be delivered to the Governor of each State in the Union for the use of the States respectively, the object being to encourage uniformity of weights and measures throughout the Union. At this time, several States had adopted standards differing from those used in the Treasury Department, but after a time these were rejected, and, finally, nearly all the States formally adopted by act of legislature the standards which had been put in their hands by the National Government. Thus a good degree of uniformity was secured, although Congress had not adopted a standard of mass or of length other than for coinage purposes as already described.

"The next, and in many respects the most important, legislation upon the subject was the act of July 28th, 1866, making the use of the metric system lawful throughout the United States, and defining the weights and measures in common use in terms of the units of this system. This was the first *general* legislation upon the subject, and the metric system was thus the first and, thus far, the only system made generally legal throughout the country.

"In 1875 an International Metric Convention was agreed upon by seventeen governments, including the United States, at which it was undertaken to establish and maintain at common expense a permanent International Bureau of Weights and Measures, the first object of which should be the preparation of a new international standard meter and a new international standard kilogram, copies of which should be made for distribution among the contributing governments.

Since the organization of the Bureau, the United States has regularly contributed to its support, and in 1889 the copies of the new international prototypes were ready for distribution. This was effected by lot, and the United States received meters Nos. 21 and 27, and kilograms Nos. 4 and 20. The meters and kilograms are made from the same material, which is an alloy of platinum with 10% of iridium.

"On January 2d, 1890, the seals which had been placed on meter No. 27 and kilogram No. 20, at the International Bureau of Weights and Measures, near Paris, were broken in the Cabinet room of the Executive Mansion by the President of the United States, in the presence of the Secretary of State and the Secretary of the Treasury, together with a number of invited guests. They were thus adopted as the National Prototype Meter and Kilogram.

"The Troughton scale, which in the early part of the century had been tentatively adopted as a standard of length, has long been recognized as quite unsuitable for such use, owing to its faulty construction and the inferiority of its graduation. For many years, in standardizing length measures, recourse to copies of the Imperial yard of Great Britain had been necessary, and to the copies of the meter of the archives in the Office of Weights and Measures. The standard of mass originally selected was likewise unfit for use for similar reasons, and had been practically ignored.

"The recent receipt of the very accurate copies of the international metric standards, which are constructed in accord with the most advanced conceptions of modern metrology, enables comparisons to be made directly with those standards, as the equations of the national prototypes are accurately known. It has seemed, therefore, that greater stability in weights and measures, as well as much higher accuracy in their comparison, can be secured by accepting the international prototypes as the fundamental standards of length and mass. It was doubtless the intention of Congress that this should be done when the International Metric Convention was entered into in 1875; otherwise there would be nothing gained from the annual contributions to its support which the Government has constantly made. Such action will also have the great advantage of putting us in direct relation in our weights and measures with all civilized nations, most of which have adopted the metric system for exclusive use. The practical effect upon our customary weights and measures is, of course, nothing. The most careful study of the relation of the yard and the meter has failed, thus far, to show that the relation as defined by Congress in the Act of 1866 is in error. The pound as there defined, in its relation to the kilogram, differs from the Imperial pound of Great Britain by not more than 1 part in 100 000, an error, if it be so called, which utterly vanishes in comparison with the allowances in all ordinary transactions. Only the most refined scientific research will

demand a closer approximation, and in scientific work the kilogram itself is now universally used, both in this country and in England.*

"In view of these facts, and the absence of any material normal standards of customary weights and measures, the Office of Weights and Measures, with the approval of the Secretary of the Treasury, will in the future regard the international prototype meter and kilogram as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the Act of July 28th, 1866. Indeed, this course has been practically forced upon this Office for several years, but it is considered desirable to make this formal announcement for the information of all interested in the science of metrology or in measurements of precision."

"T. C. MENDENHALL,

"*Superintendent of Standard Weights and Measures.*

"Approved:

"J. G. CARLISLE,

"*Secretary of the Treasury.*

"APRIL 5TH, 1893."

As a result of this action, our fundamental units of length and mass are now the new international prototype meter and kilogram preserved by the International Bureau of Weights and Measures, near Paris, and our metrology is in touch with that of the civilized world. This is the second great step towards complete emancipation from the "brain-wearying, intellect-destroying" system with which we have so long been burdened, and let us hope that the time is not far distant when the desire of the author of the Declaration of Independence will be realized by "bringing the calculation of the principal affairs of life within the arithmetic of every man who can multiply and divide."

None will be more benefited personally by this action, and none can aid more effectually to hasten it, than the distinguished body to which this paper is respectfully submitted. If any argument in its favor

* Reference to the Act of 1866 results in the establishment of the following equations:

$$1 \text{ yard} = \frac{3600}{3937} \text{ meter.}$$

$$1 \text{ pound avoirdupois} = \frac{1}{2.2046} \text{ kilo.}$$

A more precise value of the English pound avoirdupois is $\frac{1}{2.20462}$ kilo., differing from the above by about 1 part in 100 000, but the equation established by law is sufficiently accurate for all ordinary conversions.

As already stated, in work of high precision the kilogram is now all but universally used and no conversion is required.

were needed, it would be sufficient to cite the example of one department of the great subject of engineering, namely, electrical engineering, which is doubtless represented in some degree in this Congress. But, yesterday a thing unknown, its beautifully simple units of measure and their inter-relations are as wings which have enabled it to outstrip those that persist in carrying the dead weight of an unscientific and hopelessly bad system of metrology.

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HISTORICAL NOTES UPON ANCIENT AND MODERN SURVEYING AND SURVEYING INSTRUMENTS.

By H. D. HOSKOLD, M. and C. E.*

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

It would be exceedingly difficult, if not absolutely impossible, to determine how far back the nature, relation and application of lines and angles began to be studied and employed as a useful art in the graphic representation upon maps of part, or of the whole, of the earth's surface. Reference has been made to an ancient Sanscrit manuscript, in which it is stated that the Chaldeans estimated 4 000 steps of a camel to be equal to 1 mile, and that 66.25 of such miles were equal to 1°; and further, from that data, 24 000 miles were deduced as the circumference of the earth.

* Director of the National Government Department of Mines and Geology, and Inspector-General of Mines, of the Argentine Republic.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Pythagoras, Thales and Anaximander have each in turn been made to share in announcing the earth to be spherical. Archimedes estimated the circumference at 300 000 stadia, and in the year 276 B. C. Eratosthenes also determined the circumference to be 252 000 stadia; but as the exact length of the ancient stadium has not been accurately determined, no verification has resulted.

In about 52 B. C. Posidonius determined from observations made upon the star Canopius at Rhodes, and also at Alexandria, that the circumference of the earth amounted to 240 000 stadia.

Letron stated that the amplitude of the arc which Posidonius used was only 5°, and Strabo gives 400 000 stadia as the length of the arc, and also deduced therefrom that the circumference of the earth amounted to 288 000 stadia.

Ptolemy estimated 180 000 stadia as the circumference of the earth, and Posch infers that he obtained this result from ancient Chaldean data. Ptolemy also stated that a Chaldean mile was equal to 7.5 stadia, and that consequently 7.5 times 24 000 made the circumference equal to 180 000 Chaldean miles.

In the year 1827 B. C. an Arabian caliph instructed his astronomer to measure an arc of the meridian, and from that operation the circumference of the earth was estimated. In 1322 A. D. Abulfeda explained the process adopted, and stated that from the northern portion of the measured arc, 56 miles were deduced as the length of 1°, but the southern arc gave 56.66 miles as the length of 1°, the latter being equal to 71 English miles.

Referring to the question of ancient maps, we have reference to a mining map of an Egyptian gold mine constructed upon papyrus about the year 1400 B. C., which document is preserved in the Turin Museum, in Italy. In the British Museum, in London, exists also an old papyrus document written 1700 years B. C., which, however, is considered to be a copy of an older one. Its contents consist of rules for the calculation of areas of circles, triangles and trapeziums.

Hero, in his book, which was written about 285 B. C., describes such problems as were then applied to land surveying. He also introduced improvements in surveying instruments.

The great astronomer and geographer, Ptolemy, is said to have possessed a circle engraved upon stone, by which, in his observations, he estimated angular measure to single minutes. If that report is

true, we have a remarkable instance of mechanical skill and early geometrical conception and precision. Doubtless, however, the circle employed must have had a very large diameter to admit of such a degree of accuracy, because the subdivision of a degree into fractions by means of a vernier scale and micrometer was then unknown.

The well-known geometrical elements of Euclid, possessing, as they do, the basis of mathematics for all time, were probably based in part upon much older propositions of a similar nature; but he must have applied his rules to practical surveying in Egypt to a very large extent, and at a comparatively early period.

The ancient surveying instruments must have been exceedingly rude in construction, and probably consisted, for the most part, of two revolving horizontal cross-bars of wood or metal, moving round a central pin or axis mounted on the top of a perpendicular staff or rod thrust into the ground; and probably the observed horizontal angles formed by the straight lines observed between the cross-bars may have been measured by a straight line divided as a scale of equal parts, either fixed, or temporarily applied, by the observer. There is no evidence on record known to the writer, showing that circles or arcs of circles were used by the ancient observers; still, there is no reason why they should not have been.

Ogilby stated in his book of roads surveyed in 1674, that the Persian monarchs commanded an exact register to be made of the distance from station to station throughout their dominions. The great Macedonian conqueror also had his "*Mensores Itinerum Alexandri.*"

The Romans, who were at one time the conquerors of a considerable portion of the then known world, measured and recorded the length of all the principal lines of roads traveled by them in their military operations and conquests, and we know from the records constituting the ancient itinerary of Antoninus that some of these surveys ended at Alexandria along the Nile, and extended to parts of Asia and to other parts of Africa; so that if they did not possess an equal, or a superior, system of surveying to that practiced by the Chaldeans and Egyptians, they were sufficiently intelligent to adopt any other system of surveying more convenient. The itinerary of Antoninus, however, contains no evidence that the horizontal angles which existed between the different lines of roads were determined.

From the time when the Romans conquered Britain, Spain, etc., the

art of surveying apparently remained in a very rude condition for a very considerable period of time. In the time of Ferrel, it was in some measure revived and improved, and he attempted to measure a degree of the meridian between Amiens and Paris in 1525. The measuring instruments which he employed in determining the distance consisted of a revolving wheel of known circumference. His astronomical observations were made by an arc of a circle or angular instrument, then called a sector, of 5 ft. in diameter. From the operations thus conducted, he estimated the length of 1° to be equal to 365 088 English feet.

The earliest English work upon surveying known to the writer is that published by Diggs in 1550, and in it he describes a surveying circle of 24 ins. in diameter, each division of which represented 2°. It was mounted with two revolving horizontal bars, with short perpendicular plain sights fitted to the end of each bar, the whole being placed for use on the top of a staff. Diggs honored this instrument with the name "theodolite."

In the old Latin book upon mining and metallurgy published by Agricola in 1556, there is a chapter upon subterraneous surveying, and there are diagrams of the rudest classes of instruments then employed. A nude surveyor is represented in the act of taking levels with a large vertical circle, having a weighted movable index or pendulum, to determine when it was perpendicular.

Snellius is said to have commenced a system of trigonometrical surveying or triangulation as early as 1615, and he employed a chain to measure the base line. His amplitude arc was only 1° 11′ 5″ from which he deduced 55 074 toises for the length of 1°, a toise being equal to 6.3946 English ft. Afterwards his work was verified, and 1° found to contain 57 033 toises.

In the year 1655 Norwood measured with a chain the distance from London to York, and he obtained 57 424 toises for the length of 1°.

In 1681 Houghton published a small work upon subterraneous surveying, and he employed a small but rudely constructed circle mounted with a magnetic needle. Voigtel also wrote in 1586 upon the same subject.

It has been stated that Gascoign placed spider lines in the focus of a telescope attached to his surveying instruments as early as 1640, but this is somewhat doubtful. It is, however, certain that Picard applied

the telescope to angle-measuring instruments, and also placed spider lines to indicate the focus of the telescope in the year 1669. About the same time, he also measured a base line 7 miles in length, and employed an angular instrument of the sector class of 10 ft. radius with a telescope attached, and from his arc of 1° 22′ 58″, he estimated the length of 1° to be 57 060 toises.

The great mathematician and philosopher, Newton, had previously announced to the world his grand principle of universal gravitation, and he determined the form of the earth to be that of an oblate spheroid, and that consequently the equatorial axis of the earth was greater than the polar. The geodetic operations performed by Picard seem to have enabled him to establish his principles.

Between the years 1684 and 1718, the original triangulations of Picard were extended by Cassino southward to Collioure and northwards as far as Dunkirk, in France. A base line was measured at each end, and the northern portion of his arc had an amplitude of 2° 12′ 0″, from which 56 960 toises were deducted as the length of 1°. The southern arc, of 6° 19′ 0″, gave 57 097 toises for the length of 1°. The deductions thus arrived at seemed to have convinced the French that Newton's hypothesis was erroneous and serious discussions resulted between the two opposite parties. Finally, in the year 1744, the same base lines were remeasured by Cassini de Thuri and Lacaille, and from the deductions arrived at they declared that the earth was oblate, thus confirming the theory of Newton and Huygens; still, the French scientists generally were opposed, while the English as strenuously affirmed. To settle this question definitely the French agreed to undertake, in the year 1775, two scientific expeditions, one to Peru and the other to Lapland. In the latter place the angles were measured by means of a quadrant 24 ins. in diameter, fitted with a telescope and micrometer. The astronomical observations were obtained by the use of a sector 9 ft. in length. The final results deduced from these observations gave 57 437.9 toises as the length of 1° of the meridian which cuts the polar circle. Those operations were afterwards examined resulting in the length of 1° to be 57 237 toises.

The Peruvian expedition measured two bases near Quito and Cotopaxi of 7.6 and 6.4 miles, and the quadrants used for the measurement of the horizontal angles were 24 and 26 ins. in diameter; but they were of a very inferior construction. The astronomical sectors were 8 and

12 ft. radius. The length of 1° obtained was equal to 56 753 toises, and the scientific world became convinced that those deductions confirmed Newton's theory. A general account of the geodetical operations made by the two expeditions was published in France, in 1749.

It is interesting to note that Weidler published a book, in Latin, upon surveying, in 1726; and also Beyer published his work on the same subject in 1749, followed by Oppel, in German, in 1749.

The Englishman, General Roy, commenced a trigonometrical survey in Scotland, between the years 1747 and 1755; but the results were not reliable, and this induced the general opinion that surveying circles or instruments of a superior class should be constructed and introduced before accurate geodetical results could be obtained. Various surveys were, however, conducted in Ireland about 1752 and 1755, but the instruments employed were of the class known as circumferenters, very similar to that described in the old book of Diggs.

The necessity for more accurate instruments being publicly acknowledged, the celebrated Englishman, Ramsden, undertook to investigate the question, and his scientific, mathematical, mechanical and general practical knowledge led to the ever-memorable invention of his dividing engine for the purpose of graduating or dividing astronomical and surveying circles by machinery instead of by hand, as had been the case up to that time.

It is only just to remark that Bird wrote a work upon a system of graduating instruments in 1767.

The history of the progress made by Ramsden is as interesting as it is important; but it was not until he had experienced various failures that he succeeded. The division of a circle by hand before and up to the time of the discovery of the dividing engine, introduced inequality, as may be supposed, producing serious errors in the angles observed with such instruments; but the Ramsden engine reduced such inequality to a minimum, and the mechanism which he devised has not, to the knowledge of the writer, been superseded; in fact, we may go as far as to say that the division of a circle is now performed by the delicate modern dividing engine with almost mathematical precision.

The system introduced by Ramsden was soon adopted throughout Europe, and from that period geodetical surveying may be said to be placed upon a more certain and perfect basis. When the dividing engine was completed, Ramsden constructed his great theodolite of

36 ins. in diameter, the division of the horizontal circle being subdivided by means of micrometrical microscopes to read to a single second of arc. The telescope of this instrument had a focal length of 36 ins., and was the first important instrument used upon the English trigonometrical survey. Ramsden constructed a second theodolite of the same class and dimensions, which was also employed in the English geodetical operations. It is curious to note that Ramsden's first theodolite is still preserved in England in perfect condition.

In the year 1784 an English base line was measured with a steel chain which had been prepared by Ramsden, and two independent measurements of the same base were made by this chain, differing only by 1.5 in. from each other in a total distance of 5 miles. Repeated measurements of other base lines gave a less difference.

The English trigonometrical survey was delayed by the death of General Roy, and it was not until the year 1791 that it was recommenced. The detailed account of the various scientific processes adopted, and instruments employed in carrying it out, was published by Mudge & Dalby in 1799.

The repeating surveying circles employed by the French in geodetical operations were found not to be capable of competing with Ramsden's theodolite, because the peculiar construction of the former class of instrument did not insure its entire stability.

In the East Indies, in latitude 23° 18′ 0″, a degree was measured, and found to contain 56 725 toises. Laplace and Lagrange proposed, in 1791, that a standard linear unit of measure should be adopted in France, and to be made equal to $\frac{1}{10000000}$ part of the earth's quadrant, and to be called a meter. It was also proposed that the length of this quadrant should be determined by the measurement of an arc of 9° 40′ 24″, two-thirds of which was to be north of the 45th parallel, the northern terminus being Dunkirk, France, and the southern, Barcelona, in Spain. The celebrated mathematician Delambre was in charge of the former, and Mechain of the latter. The present length of the French meter is the result of their labors.

Mudge measured various base lines in England, and continued the triangulation, completing an arc of 2° 50′ 0″, from which he deduced the length of 1° in latitude 53° to be equal to 57 017 toises, and in latitude 51° it was determined to be 57 108 toises.

Biat and Arago commenced in the year 1806 to extend the triangulation from Mount Mongo, on the coast of Valencia, to Formentera, completing an arc of 12° 22′ 13.44″, the operations extending over two years. The position of Formentera was corrected by Biat in 1825, and found to differ by 9″ from the first determination.

In 1821 it was determined that the length of 1° in 45° north latitude was equal to 56 964 toises, and in 1841, Puissant discovered another error, changing the length of 1° to 57 032 toises. It is important to note that on this occasion the principle of correction by least squares was employed for the first time. Geodetic operations were not commenced in Prussia before 1802.

The Russians made some unimportant attempts to measure a base line in 1737, but no definite result was achieved. Colonel Tenner and Struve initiated a better system in 1817, and continued it until 1827. An arc of 4.5° was measured, the angles being observed by a reflecting theodolite of the French type, 16 ins. in diameter. In ten years from 1821, Struve finished an arc of 3.5°.

There being a gap between Russia and Lapland, it was determined to measure the intervening arc, and the operations were conducted by Struve and Argelander, and completed in 1844. Finally, the measurements were continued through Norway and Sweden, the operations being conducted by Struve, Selander and Hansteen. At the end of 1855 an arc of 25° 20′ 9.29″ had been completed. The Russian party employed eight base lines, 224 principal triangles, and nine astronomical determinations. The Scandinavian party used two base lines, 33 principal triangles, employing four astronomical stations.

Struve discovered that the periodic error of observation due to the mode of repetition was very considerable, and this led him to adopt the plan of measuring the same angle upon different parts of the graduated horizontal circle. The deductions arrived at by Struve from the measurement of his great arc of 25° 20′ 9.29″, were that the length of 1° in latitude 53° 20′ 0″, amounted to 57 092 toises. In 55° 34′ 0″, it was 57 166; in 56° 32′ 0″ it amounted to 57 121; in 57° 28′ 0″, it was 57 123, and in 59° 14′ 0″ it was 57 125 toises. The small number of astronomical stations selected by the Russian and Swedish Commissioners, rendered this great arc of less value than otherwise would have been the case.

In 1818 General Maufflin carried on geodetical operations with the

object of connecting Sesburg with Dunkirk, and the arc measured amounted to 8° 21′ 18″.

Brest was connected with Strasbourg by General Bonn between 1818 and 1823. The whole of the operations were carried out at night, a light being placed in the focus of parabolic reflectors for the signals at the principal stations, and the observations for the determination of the difference of longitude were aided by powder flashes.

A trigonometrical survey was made in Hanover by Gauss, who measured an arc of 2° 57′ 0″, and he calculated the length of 1° to be 57 033 toises. He also employed a heliotrope as a signal at some of the stations. The arc of 1° 31′ 53″ measured in Denmark gave 57 092 toises as the length of 1° in latitude 54° 8′ 13″.

One of the most important and extensive trigonometrical surveys on record was that commenced by Colonel Lamton in India and continued by the celebrated Colonel Everest in 1823. The latter employed a theodolite with a divided horizontal circle of 36 ins. diameter, and he extended the triangulations from 18° 3′ 0″ to 24° 17′ 0″. He was also the inventor of that beautiful type of theodolite bearing his name. This great survey was continued from 1843 to 1861 by Sir A. Waugh, and he added 8 000 miles to the Indian chain of triangles.

General Walker succeeded him, and in 13 years completed 5 500 miles of triangulations, occupying 55 azimuth stations, and determined 89 astronomical positions. The sides of the triangles employed were from 15 to 60 miles in length, and in various cases towers of masonry work were erected 50 ft. in height. Heliotrope signals were employed at the stations during the day, and Argand lamps at night.

The amplitude of the great Indian arc amounted to 23° 49′ 23.54″, but it is believed that the local attraction of the Himalayan Mountains, etc., affected the latitude and azimuth determinations. It is, however, very curious to note that when the calculated effects of such attractive forces were applied, there still existed a slight discrepancy. The principal object of this immense national survey is the formation of an exact topographical map exhibiting the area of the Empire within fixed boundary lines.

In 1871, the celebrated optician and mathematical instrument makers, Troughton & Simms, of London, constructed a new theodolite for the Indian survey, the horizontal circle of which was 36 ins. in diameter. It was very finely divided, and the graduations of the

horizontal circle were read by six principal micrometer microscopes. The telescope also had a great focal length and very large object glass. A great number of other theodolites ranging from 15 down to 5 ins. in diameter are constantly employed upon this survey. A very careful system of spirit-level operations has also been introduced, the observations being taken by instruments constructed especially large, and in this way a considerable number of elevations have been accurately determined.

During the field season of 1891, the Behar-detachment surveying party in Bengal completed a traverse survey of 1 610 sq. miles. The No. 10 party in Bombay also completed 2 536 sq. miles of detailed survey for maps on a scale of 2 ins. to 1 mile, and also 2 100 sq. miles of triangulation in the Gujaral and Mahratta country. In Burma, No. 3 surveying party completed a cadastral survey of 1 842 sq. miles, and a traverse survey of 1 142 sq. miles in the district of Shwebo, besides a topographical survey of 106 sq. miles of the Chindwin coal fields. Various other important surveys were also instituted and are at present in continuation.

The celebrated United States Coast Survey seems to have been commenced in about 1807, but a more general system was introduced in 1831. In some of the geodetical operations Borden employed theodolites with circles of 12 ins. in diameter. In 1867, from the measurement of 6 arcs, it was found that in latitude 43° and in longitude 70° 20′ 0″, the length of 1° was determined to be 111 096 m., or 57 000.3 toises. The Pamlico-Chesapeake arc of 4° 31′ 5″ was measured in 1876, and it was found that the total error due to local deflection did not amount to more than 3.5″.

The length of 1° in latitude 37° 16′ 0″ and longitude 76° 8′ 0″ was found to be 56 999 toises.

The degree of accuracy to be attained in a trigonometrical survey depends upon the precision of measurement of the primary base line, as well as the angles, and also upon the fine mathematical processes applied to reduce and adjust such discrepancies as may have arisen during the process of observing. In no country has more attention been given to the improvement and practical application of geodetic details than in the United States, as the vast amount of valuable work of this class already effected exhibits.

In the year 1834, on the great coast survey a base line was measured

at Fire Island, on the south side of Long Island, of 5.415 miles in length, in 1844 a second base line was measured in Attleboro and Sharon, Massachusetts, and a third base near the village of Epping, near Columbia, Washington County, Maine, in 1857. The distance between the Fire Island and Massachusetts bases, taken along the axial line of triangles, was 230 miles, and that between the Massachusetts and Epping bases amounted to 295 miles. An exceedingly high degree of precision was attained in those operations, for the actual measured Fire Island base differed only by 2.75 ins. from the length as calculated from the other two bases. Doubtless, when some of the more recent geodetical operations carried on in the United States are more generally made known, their precision and great importance will be thoroughly recognized by the scientific world.

The United States geodetical surveyors do not, apparently, employ theodolites of more than 12 to 14 ins. in diameter, sizes which are preferred to the larger ones.

Some of the good points requisite in theodolites of precision for geodetical operations consist of moderate lightness of construction, rigidity of parts to resist flexure and stability of working parts, accurate divisions and also subdivisions by verniers or microscopical micrometers, minimum eccentricity and great power of telescope; this should have the line of collimation made to agree with the optical axis and center of the horizontal divided circles. On no account should there exist a dead counterpoise weight on one side of the vertical circle axis, as is sometimes the case for the object of balancing the vertical circle and tangent screw apparatus. It would be far preferable to have two vertical circles with double tangent and clamp apparatus and levels. This would be a great improvement and would offer greater advantages for correct astronomical observations and other uses than is possible when only one vertical circle is attached to the instrument. It is, however, difficult to obtain an instrument which would fulfill all these conditions. The nearest approach to perfection in the construction of instruments is to be found in those made by Troughton & Simms, of London, and the opticians of the United States.

Transit theodolites of 7.5 ins. in diameter are exceedingly useful and sufficient for most ordinary purposes. In elevated regions where the air is clear and steady, as in the mountains of the Argentine Republic, such instruments would serve to observe the angles of a secondary

series of triangles in a trigonometrical survey, especially if microscopical micrometers were to be attached. Five and 6-in. theodolites are now constructed to read to 10" of arc by that means. For exploring parties in elevated regions, these instruments would be sufficient for pioneer work, and for taking simple astronomical observations for latitude and longitude.

It has been observed that the differences were so small between the steel standard chain, and glass tubes, when employed to measure a base line, that preference was given to the chain. Borda employed a measuring instrument constructed of platina and brass. Colby measured a base line in Ireland, nearly 8 miles in length, with an error of less than 2 ins. This apparatus consisted of two bars, one of iron and the other of brass, riveted together at the centers; these bars were compensating and performed excellent work.

In the United States, the measuring bar or instrument for determining the length of the base line consisted of two bars, one of iron and the other of brass, each less than 6 m. in length. Bessel's measuring apparatus also consisted of two bars, one of iron and the other of zinc.

Various classes of instruments for measuring base lines have been introduced with varying results; but many of these forms have been abandoned.

The slight discrepancy occurring in measuring the three sides of a series of primary triangles renders it necessary to employ the ordinary corrections, and also the well-known principle of least squares; but it is curious to note, that after the most refined mathematical principles were applied and allowances made for the effect of deflection produced by the attraction of the Himalaya Mountains, etc., in India, a slight discrepancy still remained, which apparently could not be accounted for.

The practice of the world in geodetical surveying is of the greatest utility as well as scientific interest to the newer countries, such as the South American Republics, which have the great advantage of being able to select the best instruments and modes where it may be necessary to carry out such operations; advantages, in point of fact, that did not exist in the time of the first observers.

Topographical and general surveying are of the greatest practical utility as primary elements in carrying out engineering works, but the old-fashioned mode of tracing contours naturally retarded these very expensive operations. Nothing could be better than a well-combined

system of direct theodolite surveying and spirit-level operations, but when the contour lines are too close together, and the scale of the map is small, the details become very confused and are lost in the drawing; besides, in intricate chains of mountains, such as those found parallel with, and on the eastern side of the Andes, if an engineer were once to enter some of those deep gorges for the object of contour surveying, he would scarcely ever come out.

Generally speaking, fine contour observations should be laid down upon a plan to a very large scale, and then reduced by photo-zincography, or by other means which are sometimes adopted on the Ordnance Survey of England.

The method of finding distances and altitudes by the stadia and telemeter processes, has found favor in various countries, and has had much application in the United States. This plan of determining distances is well known to engineers, and needs not to be described; suffice it to say, that it is vastly superior to the old modes for getting over a large area of ground in a given time.

Some have advocated micrometrical eye-pieces attached to the eye-end of a transit telescope having one or more horizontal wires placed in the focus; but this process has not produced good results in India, arising from the fact that the movable frame carrying the horizontal wires cannot be placed in the same vertical plane as the horizontal fixed wire in the focus of the telescope.*

No trigonometrical survey has, as yet, been commenced in the Argentine Republic; consequently, all the maps have been constructed from partial railway and other surveys, and from a determination of the latitude and longitude of places.

A new system of finding distances has been invented and practiced in India, with great success, by Colonel Tanner, Indian staff officer. As a preliminary, he says:

"Several delicate and expensive instruments were already at hand with micrometrical eye-pieces attached, by which, when used in conjunction with bars of known length, horizontal distances could be measured more or less near the truth; but such instruments were too complicated and delicate in their parts to bear the rough treatment they might receive at the hands of the native establishments to whom I had mostly to look when conducting the Himalayan survey. Besides this drawback, I have not found micrometrical instruments capable

*In the United States the three cross-bars are placed on the same frame or diaphragm.

of yielding results sufficiently accurate for the purpose of obtaining traverse distances within the prescribed error admissible for work on a large scale of 56.7·ins. to 1 mile, which was laid down for the more open parts of the country that would come under my measurements."

The Colonel then describes his process of bar-subtense, which consisted in setting up a wooden bar of 20 ft. in length at any distance horizontally, and then observing the intervening angle, and calculating the distance by a well-known simple trigonometrical rule.

Each end of the bar-subtense was mounted with a circular disc, 12 ins. in diameter, to the center of each of which the vertical wire of the theodolite telescope was directed. He states that under favorable conditions of light and atmosphere a skilled observer could obtain a 3-mile distance to within 6 ft. of error; also, that a 10-ft. horizontal bar would give good results up to 1.5 miles.

The Colonel seems to have experimented with bars down to a 2-ft. Gunther's scale, blackened at the ends with 2-in. discs, and he states that he obtained good results for a 20-chain distance. He gives the following example of calculation :

Bar = 20 ft. =	30.3 links	...........Log....	1.48144
Observed angle =	20′ 11.9″	...........Co. sec.	2.23122
Log. distance =	51.60. chains	....	3.71266

It is evident that this plan would be facilitated by forming a table of distances of, say, from 2 to 200 chains and for such angles as would be employed.

Colonel Tanner states that it is an error to suppose that a distance cannot be found correctly because the angles are very small and the relation of the sides of the triangle does not approach to that of an equilateral triangle; and he further states that the results to be obtained are superior to any other short of a trigonometrical survey.

The writer has calculated a table of distances for a series of given angles and a bar subtense of 25 m. Table No. 1 commences at 0° 10′ 0″ and proceeds to 0° 10′ 25″ and the corresponding distances are 8 594.38 and 8 250.60 m., respectively. Distances are given for each second of arc, and the difference in distance for 1″ between 0° 10′ 0″ and 0° 10′ 1″ is equal to 14.30 m., and that between the angles of 0° 10′ 24″ and 0° 10′ 25″ is 13.23 m. The increment of 0° 0′ 0.1″ in the former is 1.430 m.,

and for the latter it is 1.323m., and the increment for any other part of 1" may be easily found.

Table No. 2 has been calculated for horizontal angles from 0° 15′ 0" up to 0° 15′ 25", the distance for each being 5 729.73 and 5 574.75 m., respectively. The difference in distance between the angles 0° 15′ 24" and 0° 15′ 25" is 6.02 m., and the increment for 0° 0′ 0.1" is 0.602 m.

Table No. 3 commences from 0° 20′ 0" to 0° 20′ 25", and the difference in distance between the angles 0° 20′ 24" and 0° 20′ 25" is 3.21 m., and for an increment of 0° 0′ 0.1" is 0.321 m.

We observe that the difference in the distance decreases with the increase of the angle, and for this reason when very small angles are observed, say, less than 10′, an instrument very finely graduated and mounted with a powerful telescope would be required. A 9 or 12-in. transit theodolite could be constructed to read by micrometrical microscopes to a decimal part of a second, and good results could be obtained without expending time and money in the measurement of a base line.

TABLE No. 1.

Observed Horizontal Angles.	Constant Base or Subtense.	Logarithmic Sines.	Logarithmic Secants.	Calculated Distance.	Difference in Distance.
0° 10′	25	7.4637255	2 5362745	8594.38	
0 10 1"	25	7.4644487	2.5355513	8580.80	14 30
0 10 2	25	7.4651707	2.5348293	8565.83	14 25
0 10 3	25	7.4658916	2.5341084	8551.62	14.21
0 10 4	25	7.4666112	2.5333888	8537.46	14.16
0 10 5	25	7.4673296	2.5326704	8523.35	14.11
0 10 6	25	7.4680469	2.5319531	8509.25	14.10
0 10 7	25	7.4687629	2.5312371	8495.27	13.98
0 10 8	25	7.4694778	2.5305222	8481.30	13.97
0 10 9	25	7.4701915	2.5298085	8467.37	13.93
0 10 10	25	7.4709041	2.5290959	8453.48	13.89
0 10 11	25	7.4716154	2.5283846	8439.65	13.83
0 10 12	25	7.4723257	2.5276743	8425.89	13.76
0 10 13	25	7.4730347	2.5269653	8412,14	13.75
0 10 14	25	7 4737426	2.5262574	8398.40	13.74
0 10 15	25	7,4744493	2.5255507	8384.76	13.64
0 10 16	25	7 4751549	2.5248451	8371.15	13.61
0 10 17	25	7.4758594	2 5241406	8357.58	13.57
0 10 18	25	7.4765627	2.5234373	8344 06	13.52
0 10 19	25	7.4772649	2.5227351	8330.58	13.48
0 10 20	25	7.4779650	2 5220350	8317.16	13.42
0 10 21	25	7.4786658	2.5213342	8303.75	13.41
0 10 22	25	7.4793646	2.5206354	8290.40	13 35
0 10 23	25	7.4800623	2.5199377	8277.09	13.31
0 10 24	25	7.4807588	2.5192412	8263 83	13.26
0 10 25	25	7.4814542	2.5185458	8250.60	13.23

TABLE No. 2.

Observed Horizontal Angles.	Constant Base or Subtense.	Logarithmic Sines.	Logarithmic Secants.	Calculated Distance.	Difference in Distance.
0° 15′	25	7.6398160	2.3601940	5729.73	
0 15 1′′	25	7.6402983	2.3597017	5723.24	6.49
0 15 2	25	7.6407800	2.3592100	5716.76	6.48
0 15 3	25	7.6412612	2.3587388	5710.56	6.20
0 15 4	25	7.6417419	2.3582581	5704.24	6.32
0 15 5	25	7.6422221	2.3577779	5697.94	6.30
0 15 6	25	7.6427017	2.3572983	5691.65	6.29
0 15 7	25	7.6431808	2.3568192	5685.37	6.28
0 15 8	25	7.6436593	2.3563407	5679.12	6.25
0 15 9	25	7.6441373	2.3558627	5672.87	6.25
0 15 10	25	7.6446149	2.3553851	5666.63	6.24
0 15 11	25	7.6450918	2.3549082	5660.42	6.21
0 15 12	25	7.6455683	2 3544317	5654.20	6.22
0 15 13	25	7.6460442	2.3539558	5648.02	6.18
0 15 14	25	7.6465196	2.3534804	5641.84	6.18
0 15 15	25	7.6469945	2.3530055	5635.67	6.17
0 15 16	25	7.6474689	2.3525311	5629.51	6.16
0 15 17	25	7.6479428	2.3520572	5623.38	6.13
0 15 18	25	7.6484161	2.3515839	5617.25	6.13
0 15 19	25	7.6488889	2.3511111	5611.14	6.11
6 15 20	25	7.6493613	2.3506387	5605.04	6.10
0 15 21	25	7.6498331	2.3501669	5598.95	6.09
0 15 22	25	7.6503043	2.3496957	5592.88	6.07
0 15 23	25	7.6507751	2.3492249	5586.82	6.06
0 15 24	25	7.6512454	2.3487545	5580.77	6.05
0 15 25	25	7.6517151	2.3482849	5574.75	6.02

TABLE No. 3.

Observed Horizontal Angles.	Constant Base or Subtense.	Logarithmic Sines.	Logarithmic Secants.	Calculated Distance.	Difference in Distance.
0° 20′	25	7.7647537	2.2352463	4297.24	
0 20 1′′	25	7.7651154	2.2348846	4293.51	3.69
0 20 2	25	7.7654769	2.2345231	4289.98	3.57
0 20 3	25	7.7658380	2.2341620	4286 42	3.56
0 20 4	25	7.7661989	2.2338011	4282.86	3.56
0 20 5	25	7.7665594	2.2334406	4279.30	3.56
0 20 6	25	7.7669197	2.2330803	4275.76	3.54
0 20 7	25	7.7672797	2.2327203	4272.22	3.54
0 20 8	25	7 7676393	2.2323607	4268.68	3.54
0 20 9	25	7.7679987	2.2320013	4265.15	3.53
0 20 10	25	7.7683577	2.2316423	4261.63	3.52
0 20 11	25	7.7687165	2.2312835	4258.11	3.52
0 20 12	25	7.7690750	2.2309250	4254.59	3.52
0 20 13	25	7.7694332	2.2305668	4251.08	3.51
0 20 14	25	7.7697910	2.2302090	4247.58	3.50
0 20 15	25	7.7701486	2.2208514	4244.08	3.50
0 20 16	25	7.7705059	2.2294941	4240.59	3.49
0 20 17	25	7.7708629	2.2291371	4237.11	3.48
0 20 18	25	7.7712196	2.2287804	4233.63	3.48
0 20 19	25	7 7715760	2.2284240	4230.15	3.48
0 20 20	25	7.7719332	2.2280668	1226.69	3.46
0 20 21	25	7.7722880	2 2277120	4223.23	3.46
0 20 22	25	7.7726435	2.2273565	4219.78	3.45
0 20 23	25	7.7729988	2.2270012	4216.34	3.44
0 20 24	25	7.7733537	2.2265463	4213.01	3.33
0 20 25	25	7.7737084	2.2262916	4209.80	3.21

Such determination of distances could not be approached in point of accuracy by ordinary chain measurement. Naturally the bar-subtense, or, as it may be termed, constant base, should be laid horizontal; and where the ground is irregular, it would have to be elevated so as to be within view of the engineer. It should be brought in a position correctly at right angles to the line to the observer. If a telescope were to be mounted at the middle of the bar-subtense, the assistant would be able to bring it into a proper position. A little practice would conduce to the achievement of this.

It has been proposed to determine the topographical features of the country by observations taken from a captive balloon by means of photography, but there would be some difficulty in steadying a balloon over a central point, except perhaps in very calm weather. The district commanded by the camera lens would have to be determined upon the surface so as not to produce overlapping when the balloon was removed to adjacent districts.

Originally, the comparatively rough trigonometrical and other surveying operations were very laborious and tedious, frequently introducing inaccuracy in the general deductions; especially was this the case before the invention of logarithms and logarithmic sines and co-sines. If we go no farther back than 1610, the mathematical tables published up to the present time are numerous; but some of the larger and more important works, such as Gardiner, 1642; Taylor, 1792, and Vega's 10-figure logarithms, published in 1791, have become very scarce.

The greatest masterpiece of work of this class, known to the writer, is that published by General Shortridge in 1873, which contains logarithmic sines, co-sines, etc., to every second of arc. This table extends to 597 pages. We now possess, therefore, means of a very comprehensive nature, by the aid of which we can perform a greater amount of arduous labor with greater facility and certainty and under more favorable circumstances than heretofore. The practice of astronomy, geodesy, navigation and general surveying is therefore a very different thing to what it was in ancient times.

Babbage mentions that there exists in the Paris observatory manuscript tables of logarithms calculated to a large number of decimal places, and he calls it a "Treasure of Calculations."

Mining surveying is extensively practiced in the countries where the mining industry has been followed. It is not only of great impor-

tance for the object of forming under-ground plans which should accurately represent subterraneous workings, but it is frequently applied in order to determine the position, direction and length of underground galleries or tunnels which may be necessary to be constructed for the more economic extraction of the minerals. Frequently such tunnels have to be driven from two opposite points at the same time upon horizontal, slow-inclined and curved planes, and then the art of surveying is rigidly put to the test. The accuracy of the meeting points of the axial line of the tunnel will depend upon the class of instrument employed, the system adopted, and the amount of care observed in the measurement of angles and lines,

In England, Fenwick was the first to introduce a general system of mining surveying in 1801, but it depended upon the use of the magnetic needle or instrument called Miner's dial. Fenwick, however, mentions a plan of observing horizontal angles upon the graduated circle of a circumferenter with vernier, which system he called "Fast needle." This instrument was necessarily very coarse, and when it was necessary to connect the underground workings with the surface, the magnetic needle had to be employed. Several other succeeding writers advocated the use of the miner's compass which is still, unfortunately, too much employed.

The writer published a treatise upon mining surveying in 1863, introducing a specially constructed transit theodolite for observing the vertical and horizontal angles. The first line in the survey generally connected with a shaft was taken as an assumed meridian for plotting the work on a plan, all the horizontal angles being reduced to this line and plotted by one setting of a circular protractor, or, which was more preferable, by co-ordinates. A table of these was prepared and published by the writer in the work referred to; consequently, trigonometrical calculations were very much facilitated. This surveying book was employed as a class-examination book in various collegiate institutions of London, the system inculcated creating, so to speak, a new school of mining surveyors.

The plan recommended in this book for connecting the underground workings, or first line in a tunnel, to the surface, was by means of direct telescopic sight up or down a shaft, and also by suspending chains when the depth was not very great.

In March and August of 1856, the celebrated civil engineer, Arthur

Beansland, introduced a similar system which was discussed in the Institute of the North-of-England Engineers. He made the connection of an underground line to the surface, or *vice versa*, by means of direct telescopic vision down a shaft, the vertical wire in the focus being made to coincide with the underground line. For this process he employed a very powerful transit instrument. The particulars of his system were published in Vol. IV of the *Transactions* of the Society of Engineers before referred to.

This system has not become general in England, for the reason, the writer thinks, that every mining surveyor may not find it convenient to purchase an expensive transit instrument which is not useful in general surveying, and from the fact that general surveying theodolites are not constructed in such a form as to admit of their being employed for this important operation.

Some years since the writer suggested to Messrs. Troughton & Simms, of London, that the vertical axis of the horizontal plates of the theodolite should be made larger and perforated so as to admit of a direct sight of the telescope down a shaft; but the design of the instrument was lost in Paris, and consequently allowed to lapse. Recently the subject was rediscussed with the same opticians, who have actually made instruments of this class for the Cape of Good Hope Survey, the idea being that the center of the theodolite may be more accurately set up over a station.

In France and the United States, theodolites are sometimes constructed with an additional telescope, which is fixed at the end of the horizontal axis carrying the ordinary telescope. Sometimes, also, the Y's supporting the horizontal axis and telescope are bent forward so as to admit of a direct sight being made by the telescope down a shaft; but the writer believes that these modes of construction are clumsy, inconvenient and unsightly.

The first notice known to the writer of a similar mode of connecting the first line in an underground tunnel to the surface, or *vice versa*, is to be found at pages 249 and 250 of "Bourne's Survey," published in 1843, or 13 years before Mr. Beansland published his system. The method indicated by Bourne was employed in constructing the Box tunnel on the Great Western Railway in England. The shafts sunk upon the line of tunnel were from 300 to 400 ft. deep, and 20 ft. in diameter, and the theodolite was placed on each side of the shaft in succession in the

line of the tunnel; sights were then taken down the shaft and two permanent marks placed at the bottom; a line was then stretched through the marks which indicated the direction of the tunnel. Naturally this operation was repeated, and the direction checked. Browne says that when shafts are too deep, a transit instrument should be employed. This system has been much employed for railway tunnels in England.

The Severn tunnel, in England, was 2 miles in length, and shafts were put down upon it at each end or side of the river. From the top of the shafts sights were taken downward by a powerful transit instrument placed in the line of the tunnel at the surface; thus, a portion of the tunnel, 12 ft. in length, was produced at the bottom of the shaft; a wire was then stretched in the direction indicated by the vertical wire in the focus of the telescope, the wire being illuminated by electricity. It was fastened at one end and weighted at the other, and adjusted in the proper direction by lateral screws. When 100 yds. of the tunnel had been driven, its direction was again verified by observing with a transit telescope. When the tunnel met from the two ends no difference could be perceived.

The writer has executed tunnels in iron and coal mines by this means, having for a base in the bottom of the shaft, a distance of not more than 7 ft., and the error at the meeting points was inappreciable. Doubtless, excellent work has been done in the United States by this system, but the writer has no special information at hand, and is consequently unable to refer to it.

Some years since the writer also introduced a new mining and general surveying theodolite. It has two telescopes, one works in the center of the axis attached to the lower divided limb, and its optical axis coincides with the zero on that limb. The optical axis of the upper telescope coincides with the zero of the upper vernier horizontal circle. There is, therefore, no occasion to bring the zeros into coincidence. The advantages of this theodolite are various; it can be employed as a transit theodolite, and it is exceedingly useful in setting out land for colonies or locations when the lines forming the area are at right angles. Plates I and II represent a theodolite of this class of the ordinary type. Recently, however, it has received various improvements, and one of the most recently constructed types is exhibited in the British Section of the World's Columbian Exposition.

PLATE I.

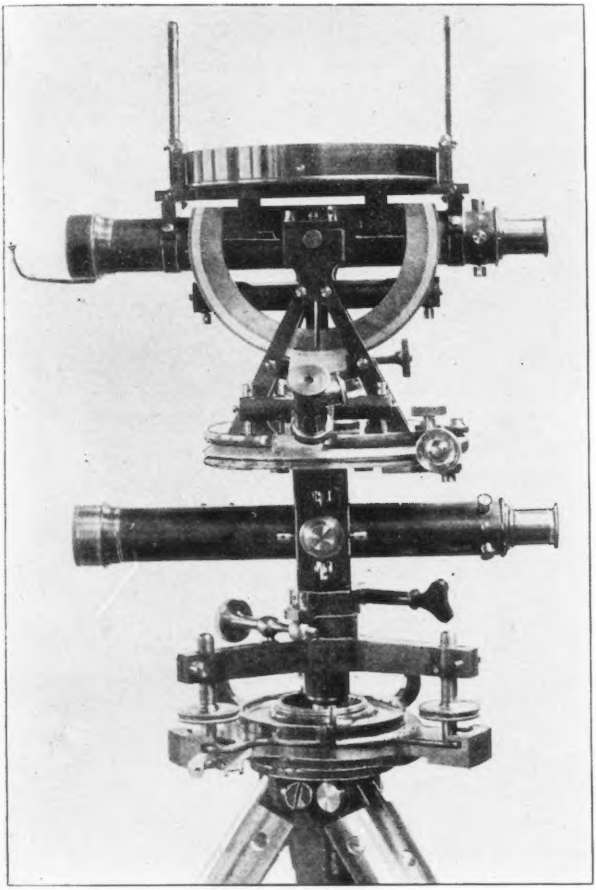
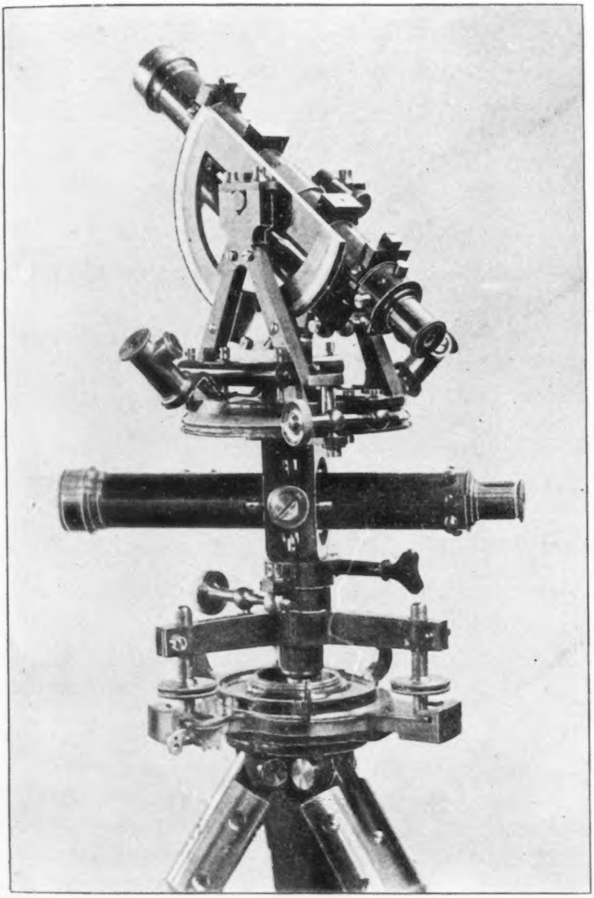


PLATE II.



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THE TREATMENT OF METALS FOR STRUCTURAL PURPOSES.

By JAMES CHRISTIE, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The evidence is now almost conclusive that wrought iron, as produced by the puddling process, will be largely supplanted for structural material by steel or ingot metal, as produced by fusion at high temperature. Public confidence is now fairly established in the trustworthiness of this material; the doubts of many have been gradually dissipated by the result of experience, and the manipulation of steel in all stages of its manufacture admits of such rapidity and economy of production that it will probably control future demands as the most desirable form of structural metal.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Hence, steel is the metal given prime consideration in this paper.

Whether blown in the Bessemer converter, or boiled in the open hearth, or whatsoever refractories may be used to facilitate desirable reactions or combinations, the general characteristics of the metal remain identical. The engineer demands results of the highest standard, without stipulating how these results may be produced; and he is only justified in specifying a certain process of manufacture, or the limitation of certain combining elements, when it is definitely known that the system specified yields more certain and uniform results than otherwise. In the open-hearth process the character of the product can be so readily controlled and predetermined, that, when metal of definite uniform composition is desired, experience favors the latter rather than the pneumatic process. On the contrary, when a large output is required of a grade readily obtained from the converter, with moderate uniformity, the Bessemer process takes precedence.

Prevalent opinion and practice favor the use of steel in structures varying between 60 000 and 70 000 lbs. tensile strength per square inch of sectional area. For special purposes, as in rivets, etc., a weaker (softer) metal is desirable; or, the known advantages of a stronger (harder) metal for compression members, etc., is an inducement to its use, the principal objection being its susceptibility to hardening influences, which in ordinary methods of production may result in sufficient hardness to render cutting processes difficult, or in extreme cases material may be in a doubtful condition for service in structures. Again, as the several grades possess a uniform coefficient of elasticity, the seeming advantage of high tensile strength is not always available, owing to necessary limitation of extension or compression and deflection. The adoption of a uniform grade for general purposes would simplify inspection, lessen the chances of the various grades being misapplied, and contribute to economy of production.

Hardening Tests.—The table gives results of a current series of hardening tests of O.-H. steel, made on silica bottoms. Three-inch ingots were hammered to a uniform section of ¾ in. square, then reheated to a bright red, and quenched in water of about 80° Fahr. The specimens thus hardened were bent with a light power-hammer to a U shape, the radius of bend being not greater than thickness of specimen. All specimens below .13 carbon bent without cracking; all above .23 carbon broke. Tensile tests for steel treated in this manner are given hereafter.

Carbon per cent.	Number bent without crack.	Number cracked.	Number breaking.	Per cent. without crack.	Per cent. cracking.	Per cent. breaking.
.13	17	1	0	94.4	5.6	0
.14	32	5	0	86.5	13.6	0
.15	30	6	2	78.9	15.8	5.3
.16	40	10	3	75.5	18.9	5.6
.17	35	18	7	58.3	30	11.7
.18	18	11	7	50	30	19.4
.19	16	5	14	45.7	14.3	40
.20	5	3	12	25	15	60
.21	4	5	6	26.7	33.3	40
.22	4	3	4	36.4	27.3	36.4
.23	1	0	7	11.5	0	87.5

It is not intended here to discuss the quality of steel as determined by the component elements, a subject which has received ample attention at the hands of competent investigators. Suffice it to say, that it is generally recognized that phosphorus and sulphur exercise an influence entirely evil, especially the former in its effects on material when in service. If the manufacturer could banish them entirely, he would do so.

Conservative specifications usually limit both these elements from .08 to .10% for O.-H. steel by acid process or one-third less for metal made on basic linings. Manganese is a necessary corrective, and is usually present to the extent of .4 to .6%, and, if ferro-silicon is used in the manufacture, silicon may be found from .10 to .15% without any known disadvantage. Carbon will vary from .15 to .25% in the structural steels under consideration.

It is desirable that the cast ingots should solidify thoroughly as porosities are apt to develop into seams and flaws, and central cavities or "piped ingots" may leave concealed fissures in finished work. To promote soundness, the fluid steel, if made in the open hearth, should remain in the furnace until ebullition subsides as far as practicable. The addition of certain reagents, notably ferro-silicon, or minute quantities of aluminum, has a decided effect in repressing the effervescence. Bottom pouring also contributes towards solidity, and the ingots should be kept in a vertical position until solid, to prevent the formation of longitudinal cavities in the fluid interior.

If before rolling, the ingots should have lost the initial heat, it is preferable to reheat slowly in a furnace of moderate temperature, as cracking is liable to ensue if cold ingots are charged into a very hot furnace.

The limit of high temperature for rolling or forging is imposed on the workmen by the necessities of the case, as excessive or prolonged overheat will result in rupture of the ingot when reduced in the mill.

In the rolling process, especially for bars of a flanged section, the manufacturer is controlled by the necessity of maintaining a proper distribution of the metals in the successive passes through the rolls; the natural flow of the heated metal should be followed by suitable shaping of the successive grooves, so that, so far as possible, all surfaces should be acted on by the roll, preventing cracking of edges, or rupture by unequal tension.

The temperature at which finished product leaves the rolls exercises some influence on its molecular structure. There is but little possibility of metal being worked at too low temperature, but if rolling ceases at too high temperature, it is claimed that a more open grain, or coarser crystallization than otherwise, is observable in fractured steel, with reduced ductility exhibited by tensile test. A similar result is sometimes found with iron where bars of large section finished very hot, when nicked with a chisel and bent, break with crystalline fracture, the fracture being fibrous if the same bars are reduced to smaller section, or if annealed. This has been repeatedly demonstrated, but it is not definitely known whether the condition described may not be due to a peculiarity of certain metals, rather than a property of all forms of malleable iron, or that the effect may be due to prolonged heating, as some experiments described hereafter at least imply a doubt on the subject. Whatever the cause, the final condition of tension bars of unusually large section should be a matter of solicitude to the inspector, and it is probable that such bars, whether of steel or iron, are benefited by final annealing.

The material should be delivered from the rolls, so as to require the least amount of cold straightening. When cold straightening is necessary, it should be done by rolling process rather than by the bending press. No injury has been found to result from roller straightening, and it is quite probable that its effect on the material is in a minor degree very similar to the well-known process of cold rolling.

Testing.—The testing of material may be either for the purpose of ascertaining its quality, or the physical effects produced by treatment subsequent to rolling. It is desirable always to select material in the

condition in which it enters the structure, and to avoid the destruction of a considerable quantity of material it is the usual custom to cut selected specimens that will, as fairly as practicable, represent material under inspection. A specimen from each melt may fairly represent the material in all the ingots cast from that heat, but a specimen from each charge of a reheating furnace would furnish little indication of the effects of reheating on the whole charge. To obtain this result it is evident that a specimen from each separately heated bloom would be necessary. It is evident that this is a matter that depends on the critical inspection desired by the purchaser, and will be a subject of mutual agreement between him and the manufacturer. Considerable confidence must be placed on the skill and honesty of manufacturers and workmen of established reputation.

Tension tests by the well-known process afford satisfactory evidence of the tensile strength and ductility of material. Drifting and bending tests are a ready and efficient means of testing ductility, that appeal to the eye and judgment, but as ordinarily practiced do not yield a result capable of being precisely recorded. Quenching heated specimens in water and bending, give evidence of the existing extent of hardening property, and the drop gives the crucial test of ability to resist shock and violence.

The various methods of testing material are so well understood, and so extensively practiced, that no radical innovation on current practice can be suggested. But if rapid testing of every piece separately rolled is desired, it may be suggested that a cropping from each piece could be mechanically punched and drifted, so that the resistance to drifting could be accurately recorded and interpreted into a reasonable measure of tensile strength, while the amount of dilation, previous to fracture, affords an approximate estimate of ductility.

The table on the next page gives the general physical properties of steel between extremes of 60 000 and 70 000 lbs. tensile strength. They are the combined averages of a series of current tests of material of approved quality, and embrace results of about 100 consecutive tests.

Shop Treatment.—It has heretofore been the usual custom to use the punch and shears for the preparation of structural iron. As steel became extensively used an impression gained that similar treatment was especially injurious to this metal, and as long as the raw material was of greater pecuniary value than iron there existed considerable disinclina-

ROLLED STEEL.

Tensile strength in pounds per square inch.				Elong. per cent.			Red. of Area		
Ultimate.	Elastic Limit.			In 8 ins.			Per Cent.		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
60 000	44 070	30 530	38 170	32	24	27.6	65.3	47.2	56.5
62 000	43 580	36 530	39 010	32	25	27.2	69.9	27	57.8
64 000	45 190	36 530	39 980	30.5	23.7	26.0	65.5	52.16	55.5
66 000	45 020	37 860	41 000	39.75	25.5	27.2	64.3	47.1	54.7
68 000	45 460	38 900	41 070	52.5	22.5	27.8	61 5	24	50.7
70 000	45 990	38 969	43 270	28.25	22	24.9	59.8	36.5	52.1
72 000	47 200	39 440	44 030	27	20.7	24.8	58	31.7	51.3

tion to use it unless all cut edges were planed, and holes either reamed after punching or drilled from the solid. There is no doubt that steel of higher tensile strength than is now accepted for structural purposes should not be punched or sheared, or that the softer material may contain elements prejudicial to its use however treated, but especially if punched. But extensive evidence is now on record, indicating that steel of good quality, in bars of moderate thickness, and below or not much exceeding 80 000 lbs. tensile strength, is not any more, and frequently not as much injured as wrought iron by the process of punching or shearing.

In addition to minor data on the subject, published in the technical journals, reference is made to a compilation of recent data by F. H. Lewis, C. E., in the "Proceedings of the Engineers' Club of Philadelphia," January, 1892. There is also subjoined the results of a series of experiments made within the past two years under the observation of the writer. The latter were made by skilled operators with the sole intention of getting the facts of the case.

General Effects of Shearing and Punching.—The cutting tool compresses or displaces the material immediately at the edges cut, slightly reducing the thickness, the amount of reduction being dependent upon the thickness of the material cut. Iron sheared in the direction of the fibers is usually much more roughened than when cut across the fibers. Steel usually shows a much smoother sheared edge than iron, but sometimes very minute cracks are observable across the edge of sheared steel. It is known that the effects of the disturbance are very superficial, as the removal of the visible

roughness by planing or reaming respectively for sheared and punched surfaces apparently re-establishes the original condition. The physical effects of punching and shearing as denoted by tensile test are for iron or steel:

Reduction of ductility.

Elevation of tensile strength at elastic limit.

Reduction of ultimate tensile strength.

In very thin material the superficial disturbance described is less than in thick; in fact, a degree of thinness is reached where this disturbance practically ceases. On the contrary, as thickness is increased, the injury becomes more evident.

The effects described do not invariably ensue; for unknown reasons, there are sometimes marked deviations from what seems to be a general result.

By thoroughly annealing sheared or punched steels the ductility is to a large extent restored, and the exaggerated elastic limit reduced, the change being modified by the temperature of reheating and the method of cooling. See experiments on annealing hereafter. The appearance of the fracture is appended to some of the records.

Fractured sections of steel may exhibit either a clear crystalline structure, or a dull semi-fibrous appearance, usually known as "silky," and especially observed in bars of uniform section, which, when pulled apart, stretch considerably and show considerable reduction of the fractured area, generally also breaking with a raised and depressed coning or a beveling of the broken surfaces. The character of the fracture is to some extent indicative of the method of fracture, or of how fracture is begun, rather than quality of material. Bars nicked and broken transversely show a crystalline fracture, as may also punched bars of considerable thickness when pulled to rupture, while the same punched bars reamed may exhibit a silky fracture when pulled. Illustration of this action is given hereafter. It will be observed that the disturbance of the material by the treatment, especially by shearing, was much greater in the tested specimens, than would occur ordinarily in practice, owing to the extent of disturbed surface being large in proportion to the limited dimensions of the specimen. The effects of treatment, as denoted in the experiments, are therefore an exaggerated record of what ordinarily occurs in practice.

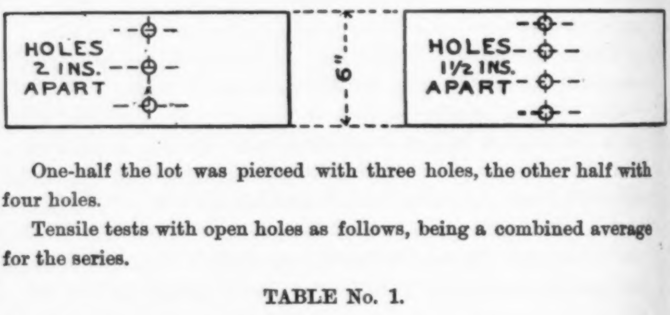
Terms are abbreviated as follows:

Ultimate tenacity in pounds per square inch of original section.................................. T. S.
Tensile strength at elastic limit in pounds per square inch of section.......................... E. L.
Stretch per cent. in 8 ins. of the fractured specimen St.
Reduction per cent. of fractured area.............. Red.

The elastic limit was recorded at the point when the scale beam dropped, sometimes given as the yield point. Stretch measured in a length of 8 ins., excepting perforated specimens, when it is measured in 2 ins., unless otherwise stated.

A series of 42 tests was made on steel plates 6 ins. wide, $\frac{1}{4}$, $\frac{5}{16}$ and $\frac{3}{8}$ in. thick, with holes $\frac{11}{16}$, $\frac{13}{16}$ and $\frac{15}{16}$ in. diameter pierced across the width as denoted below.

FIG. 1.



One-half the lot was pierced with three holes, the other half with four holes.

Tensile tests with open holes as follows, being a combined average for the series.

TABLE No. 1.

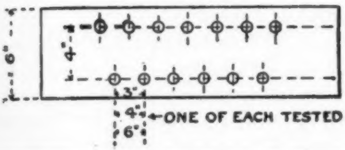
Treatment.	T. S.	E. L.	St. Per Cent.
As rolled......................	62 100	39 800	28.6 in 8 ins.
Punched......................	66 400	50 300	11.5 in 2 "
Punched and annealed,........	66 560	42 450	15.2 in 2 "
Drilled	67 000	51 370	15.1 in 2 "

The abrupt reduction of sectional area on the line of the holes accounts for the elevation of tensile strength per unit of net section above that of the original bars.

TABLE No. 2.

IRON PLATES TESTED WITH OPEN HOLES.

FIG. 2.



Original strength of the plate, an average of one test of each thickness.

T. S.	E. L.	St.	Red.
53 000	32 800	18.2	.28

Thickness.	Holes.	No. of Tests.	Total Load.	Per square inch. Max. Load.	Per square inch. E. Limit.	St. per cent. in 8 ins.
⅜	Punched 13/16"	3	82 016	32 373	29 050	4.1
⅜	Punched 11/16", Reamed 27/32"	3	97 800	38 720	28 070	6.2
⅜	Punched ¾", Reamed 27/32"	3	95 766	37 850	28 550	5.1
⅝	Punched 13/16"	3	101 183	31 490	27 800	4.46
⅝	Punched 11/16", Reamed 27/32"	3	121 233	37 890	26 483	7.43
⅝	Punched ¾", Reamed 27/32"	3	123 183	38 600	27 680	6.8
¾	Punched 13/16"	3	121 266	31 746	27 963	4.76
¾	Punched 11/16", R-amed 27/32"	3	142 166	36 950	27 436	5.86
¾	Punched ¾", Reamed 27/32"	3	144 833	37 816	26 286	6.9

TABLE No. 3.

STEEL PLATES TESTED WITH OPEN HOLES. ONE OF EACH TESTED.

Dimensions and Arrangement of Holes the same as in Fig. 2.

All bars rolled from one billet, the average of a test from each thickness, resulted as follows:

T. S.	E. L.	St.	Red.
64 300	39 300	28.9	57.3

Carbon, .16; Phos., .077; Mang., .51.

Thickness.	Holes.	No. of Tests.	Total Load.	Per square inch. Max. Load.	Per square inch. E. Limit.	St. per cent. in 8 ins.
⅜	Punched 13/16"	3	116 283	47 563	34 040	7.46
⅜	Punched 11/16", Reamed 13/16"	3	131 850	54 373	32 703	10.53
⅜	Punched ¾", Reamed 13/16"	3	130 600	53 063	32 766	10.7
⅜	Drilled 13/16"	3	134 166	54 550	32 373	11
⅝	Punched 13/16"	3	143 266	46 276	32 643	7.3
⅝	Punched 11/16", Reamed 13/16"	3	170 850	54 620	31 560	10.6
⅝	Punched ¾", Reamed 13/16"	3	157 800	50 410	31 680	9.9
⅝	Drilled 13/16"	3	169 933	54 413	31 620	11.43
¾	Punched 13/16"	3	151 400	40 103	32 700	4.96

TABLE No. 4.

A series of 12 tests, made on steel bars 4½ ins. wide and $\frac{11}{16}$ in. thick, in all respects like Tables 2 and 3, except that the parallel rows of holes were 2¼ ins. apart, resulted as follows:

	T. S.	E. L.	St. in 8 ins.	Red.
Bars as rolled............	62 800	37 200	27.8	52
Punched $\frac{15}{16}$'............	40 800	35 100	1.7	
Punched ¾" } Reamed $\frac{15}{16}$" }	51 900	31 400	12.5	

In this instance every punched bar broke with a crystalline fracture, and every reamed bar with a silky fracture.

In the three foregoing cases, as the holes in specimens were not on the same line at right angles to length of bar, the effective net section was taken as the product of thickness and width of bar, less the diameter of one hole. But owing to eccentricity of strain, the specimens always broke by starting at one edge and tearing across, which accounts for the tensile strength of perforated bars being apparently so much less than the original.

TABLE No. 5.

Effect of Punching, Punching and Reaming and Drilling Steel Bars.

Bars rolled 3 ins. wide, with holes perforated through middle of bar and treated as described, gave tensile tests as follows:

Size of bar. Inches.	Treatment.	T. S.	E. L.	St.	Red.	Fracture.
3 x ⅜	As rolled	65 900	41 800	29	54	Silky.
	Punched 1"	60 800	46 100	11	13	"
	Punched ⅞" } Reamed $\frac{15}{16}$" }	52 600	39 500	12	32	"
	Drilled 1"	65 500	45 000	15	29	"
3 x ⅝	As rolled	61 900	36 400	31	53	"
	Punched 1"	52 300	51 100	2.3	5.6	Crystalline.
	Punched ⅞" } Reamed $\frac{15}{16}$" }	60 200	46 700	14	25	Silky.
3 x ¾	As rolled	60 300	37 300	31	49	"
	Punched 1"	46 300	44 200	7.3	3.7	Crystalline.
	Punched ⅞" } Reamed $\frac{15}{16}$" }	55 000	45 700	4	27	"
3 x ⅞	As rolled	63 100	39 900	32	55	Silky.
	Punched 1"	51 000	47 200	2.3	4	Crystalline.
	Punched ⅞" } Reamed $\frac{15}{16}$" }	65 900	49 400	14	20	Silky.
3¾ x ⅞ 4 tests of each.	As rolled	70 500	37 900	26.7	47	
	Drilled $1\frac{5}{8}$"	73 000	39 000	10		
	Punched $1\frac{3}{8}$" } Reamed $1\frac{5}{8}$" }	73 700	39 400	11		

The elongations were measured for solid bar in a length of 8 ins., for the perforated bars in 3 ins. except the last item of $3\frac{3}{4}$ x $\frac{7}{8}$ ins., in which elongation was measured in 2 ins. for perforated bars.

TABLE No. 6.

Effect of Shearing Edges.

Strips sheared lengthwise from the same bars of each thickness and tested in strips varying from $1\frac{1}{2}$ to 3 ins. wide.

All specimens cut from bars varying from 6 to 10 ins. wide.

Those with planed edges were previously sheared, $\frac{1}{16}$ to $\frac{1}{8}$ in. of material being removed by the planing.

Test No.	Steel Specimens. Thickness.	Treatment of Edges.	T. S.	E. L.	St.	Red.
	$\frac{5}{16}$"	Sheared	64 600	45 100	10.6	28
	$\frac{5}{16}$"	Planed	65 100	41 600	23.2	61.8
	$\frac{1}{2}$"	Sheared	68 800	43 600	16.1	28.3
	$\frac{1}{2}$"	Planed	69 000	43 000	25.7	57.8
	$\frac{11}{16}$"	Sheared	64 300	41 600	16.5	25.
	$\frac{11}{16}$"	Planed	61 600 Doubtful.	37 200	28.4	47.5
General average sheared edges			65 900	43 600	14.4	27.1
Planed edges			67 000	40 600	25.8	55.7

A series of strips $1\frac{1}{2}$ to 3 ins. wide, cut from iron bars 8 to 10 ins. wide and $\frac{3}{8}$ to $\frac{1}{2}$ in. thick, gave results as follows as a combined average of a dozen tests.

Test No.	Iron Specimen. Thickness.	Treatment of Edges.	T. S.	E. L.	St.	Red.
	$\frac{3}{8}$" to $\frac{1}{2}$"	Sheared	42 500	33 100	5.6	18
		Planed	48 900	31 700	12.3	24.8

A bar $\frac{11}{16}$ in. thick of 7-in. flat iron, cut and tested as follows:

Test No.	Iron Specimens Width, Thickness	Treatment of Edges.	T. S.	E. L.	St.	Red.	Fracture.
	1.5" × $\frac{11}{16}$"	Planed	47 300	Doubtful 34 200	15	21	Fibrous.
	1.6" × $\frac{11}{16}$"	Sheared	38 300	30 400	4	13	"
	2.9" × $\frac{11}{16}$"	Sheared	38 600	29 900	5	14	"

TABLE No. 7.

Strips of the given widths in following table were sheared from 7-in. steel bars ¼ and ½ in. thick. A portion of them had ⅛ in. planed from each edge, others were annealed by heating to redness and burying in dry sand, and some of the planed pieces, marked overheated, were heated to a bright yellow heat, forming scale, and cooled in the atmosphere. Tension tests resulted as follows :

Test No.	Steel Specimens. Width Thickness in inches.	Treatment of Edges.	T. S.	E. L.	St.	Red.	Fracture.
1	1.9 × ¼	Planed..................	62 200	42 800	27	60	Silky.
2	1.6 × ¼	Sheared..................	62 600	44 000	16	32	"
3	1.5 × ¼	Sheared and annealed...	63 800	44 200	22	51	"
4	1.5 × ¼	Planed and overheated..	60 700	41 100	29	60	"
5	1.9 × ½	Planed	57 300	37 200	31	59	"
6	1.6 × ½	Sheared..................	64 700	43 400	18	26	"
7	1.4 × ½	Sheared and annealed...	61 300	41 400	26	53	"
8	1.3 × ½	Planed and overheated..	61 300	37 300	30	61	"

TABLE No. 8.

Bars from same bloom, rolled 7 ins. wide, ⅜, ½ and ⅝ in. thick, all sheared lengthwise into strips and pulled as follows :

Effect of shearing steel of 80 000 lbs., T. S.; Carbon, .33; Phos., .055.

Test No.	Specimen. Width. Thickness. Inches.	Treatment of Edges.	T. S.	E. L.	St.	Red.	Fracture.
1	1½ × ⅜	Planed..................	79 200	45 800	22	51½	Silky.
2	1½ × ⅜	Sheared..................	79 700	44 500	9	23	"
3	3 × ⅜	"	79 600	43 000	14½	25½	"
4	1½ × ⅜	Sheared and annealed.	83 100	50 900	19¼	31¼	"
5	1⅜ × ⅜	Planed and overheated	82 000	46 900	22	49¾	"
6	1½ × ½	Planed,..................	78 500	39 600	26	52	"
7	1½ × ½	Sheared..................	79 400	43 400	11	15	"
8	3 × ½	"	77 700	38 800	14	21	"
9	1½ × ½	Sheared and annealed.	80 800	46 900	20	27	"
10	1⅜ × ½	Planed and overheated	80 900	43 400	22	35	"
11	1½ × ⅝	Planed................	78 600	41 800	24	45	"
12	1½ × ⅝	Sheared..................	81 100	47 200	14	14	Half crystalline.
13	3 × ⅝	"	79 600	44 400	17	19	One-fourth crystalline.
14	1½ × ⅝	Sheared and annealed..	82 300	47 400	22	37	Silky.
15	1¼ × ⅝	Planed and overheated.	80 800	49 700	26	53	"
16	1½ × ¾	Planed..................	82 200	43 500	24	50	"
17	1½ × ¾	Sheared..................	82 500	45 100	14	20	"
18	1½ × ¾	Sheared and annealed..	83 100	43 100	20	33	"
19	1 5/16 × ¾	Planed and overheated.	82 500	43 300	25	50	"

It is not known definitely known if the last specimens ¾ in. thick were from the same bloom as all the others.

The planed specimens had ⅛ in. planed from each edge after shearing.

The annealing for all specimens was done by heating to redness in

a gas furnace and burying in dry sand until cool. The process seems to have been a hardening one for this grade of steel, either due to the method of cooling, or possibly the annealing temperature may have been higher than that at which the bars were originally finished. The same effect is observed in high carbon steels, unless the piece to be annealed is carefully protected from rapid cooling, or unless it is quenched at a certain critical stage of the cooling, or as usually termed water-annealed. The specimens, marked, planed and overheated, were raised to an ordinary working temperature or yellow heat, forming scale, and cooled in the atmosphere without further work. Contrary to anticipation, the action seemed to be rather beneficial than otherwise. This grade of steel, at least if low in phosphorus, shears and punches neatly, leaving a smoother surface than ordinary iron.

TABLE No. 9.

Effects of drifting holes in bars of a uniform width of 3 ins., having both edges sheared parallel with length of bar. The punched holes were perforated with a $\frac{3}{4}$-in. punch and $\frac{13}{16}$-in. die, a drilled and a punched hole being cut through each bar, and drifted until fracture was visible :

Dimensions.		Hole.	Final diameter of hole.	Fracture.
Steel 3 x $\frac{5}{8}$"................	All edges sheared.	Punched $\frac{3}{4}$"......	$1\frac{1}{4}$"	At edge of hole.
		Drilled $\frac{3}{4}$"......	$1\frac{3}{8}$"	" "
Steel 3 x $\frac{1}{2}$"................		Punched $\frac{3}{4}$"......	$1\frac{3}{8}$"	" "
		Drilled $\frac{3}{4}$"......	$1\frac{5}{16}$"	At edge of bar.
Steel 3 x $\frac{1}{2}$"................		Punched $\frac{3}{4}$"......	$1\frac{3}{8}$"	" "
		Drilled $\frac{3}{4}$"......	$1\frac{3}{16}$"	At edge of hole.
Steel 3 x $\frac{11}{16}$"................		Punched $\frac{3}{4}$"......	$1\frac{5}{16}$"	" "
		Drilled $\frac{3}{4}$"......	$1\frac{3}{8}$"	At edge of bar.
Iron 3 x $\frac{5}{8}$"................		Punched $\frac{3}{4}$"......	$1\frac{3}{16}$"	" "
		Drilled $\frac{3}{4}$"......	$1\frac{1}{16}$"	" "

The foregoing steel was cut from the same bars tested for tensile strength on Tables Nos. 6 and 8 ; they can be compared by observing the respective thicknesses.

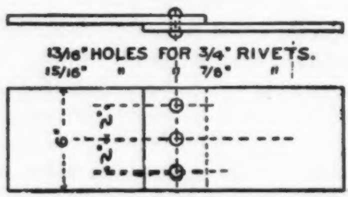
Experiments on Riveted Joints.—As the operation of riveting permanently clamps the plates together, creating a resistance to fracture of the plate independent of the force transmitted through the body of the rivet ; therefore, riveted joints can only be properly compared with each other, and not with tests of plates with open holes.

The riveted joints hereafter described were formed by lapping the ends of two plates, and fastening them with three and five rivets

respectively, as described. The object in making this imperfect joint was to obtain the distortion of the plates due to bending, when pulled in the testing machine, and thus better develop the general resisting qualities of the treated plates. As the holes were quite close together, it can be seen that the differences noted between punched and reamed joints are an exaggeration of what would occur in ordinary riveted work, or joints severed by direct tension.

TABLE No. 10.

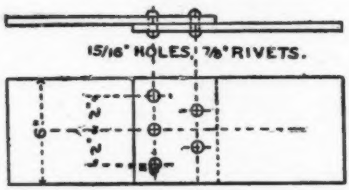
FIG. 3.



Thickness and Material.	Treatment.	Rivets.	No. of Tests.	Max. Load. Total.	Max. Load. Per square inch of net section.	Fracture.	Tests of Rolled Bars before Punching.
6 × 1/4" Steel	Punched 13/16".....	3 — 3/4"	2	57 200	67 100	Plate broke.....	T. S. = 62 900
	Reamed 13/16".....	"	1	56 600	61 000	"	E. L. = 41 600
	Punched 15/16".....	3 — 7/8"	2	59 700	78 700	"	St. = 31
	Reamed 15/16".....	"	1	56 700	68 700	"	Red. = 58
6 × 5/16" Steel	Punched 15/16".....	3 — 13/16"	2	73 300	69 100	"	T. S. = 59 800
	Punched 3/4"... Reamed 13/16"...	"	2	86 400	79 100	"	E. L. = 42 100
6 × 3/8" Steel	Punched 15/16".....	3 — 7/8"	2	78 900	73 900	"	St. = 34
	Punched 11/16".. Reamed 15/16"...	"	2	88 100	80 100	"	Red. = 61
6 × 1/2" Iron	Punched.........	"	2	71 800	46 300	"	T. S. = 54 300
	Punched and reamed 3/16".	"	2	90 000	56 400	"	E. L. = 34 800
	Reamed 1/4"......	"	2	92 000	57 700	"	St. = 17
	Drilled.........	"	2	94 900	59 500	"	Red. = 27
6 × 5/8" Iron	Punched.........	"	3	75 000	39 000	"	T. S. = 52 100
	Punched and reamed 3/16".	"	2	88 500	44 000	"	E. L. = 31 300
	Reamed 1/4"......	"	2	88 700	44 100	"	St. = 17
	Drilled.........	"	1	94 300	46 700	"	Red. = 30
6 × 3/4" Iron	Punched.........	"	2	74 000	30 700	"	T. S. = 52 800
	Punched and reamed 3/16".	"	2	96 000	38 800	Rivets sheared.	E. L = 32 100
	Reamed 1/4"......	"	2	94 100	38 900	"	St. = 20
	Drilled.........	"	2	94 800	39 100	"	Red. = 28

TABLE No. 11.

FIG. 4.

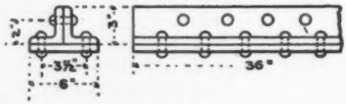


Thickness and Material.	Treatment.	Rivets.	No. of tests.	Max. Load. Total.	Max. Load. Per square inch of net section.	Fracture.	Tests of Rolled Bars before Punching.
6 × 1/2" Steel	Punched........	5 — 7/8"	2	113 600	74 000	Plate broke.....	T. S. = 64 800
	Punched and reamed 3/16".	"	2	125 100	79 300	"	E. L. = 39 800
	Reamed 1/8".... .	"	2	126 200	80 000	"	St. = 30
	Drilled..........	"	2	119 400	75 600	"	Red. = 62
6 × 5/8" Steel	Punched........	"	2	105 400	59 900	"	T. S. = 63 800
	Punched and reamed 3/16".	"	2	151 400	76 400	"	E. L. = 38 900
	Reamed 1/8".....	"	2	150 600	76 100	Rivets sheared.	St. = 28
	Drilled..........	"	2	148 700	75 200	"	Red. = 56
6 × 3/4" Steel	Punched........	"	2	89 800	38 800	Plate broke	T. S. = 64 400
	Punched and reamed 3/16".	"	2	152 000	64 000	Rivets sheared.	E. L. = 39 200
	Reamed 1/8".....	"	2	154 700	65 100	"	St. = 28
	Drilled..........	"	2	156 400	65 600	"	Red. = 54

In the Tables Nos. 10 and 11 of riveted joints, some seeming inconsistencies may be observed between the quantities given for total breaking strains and the strains per unit of net section. This arises from the fact that actual thickness and diameter of holes were properly used in estimating sections, whereas the corresponding dimensions given in the table are only nominal. Several experiments have also been made on specimens, both with open and closed holes, and submitted to transverse stress. The tests recorded herewith are typical of the series.

Six ⊥ sections composed of medium grade steel plates and angles were riveted together as follows:

FIG. 5.



Angles 3 x 3 x ½ ins., plates 6 x ½ ins.
Three specimens perforated 3 ins. pitch.
Three " " 6 " "
all rivets ⅞ in. diameter.

It can be seen that the specimens were unduly weakened by the size and position of holes. These specimens were supported 32 ins. apart and pressure applied in middle, in the position shown in cut. The load was increased until fracture began.

TABLE No. 12.

Average of Specimens with—	Final Pressure.	Final Deflection.	
Holes punched $\frac{15}{16}$"	57 600 lbs.	5.78 ins.	Edge of plate and angle cracked.
Holes punched $\frac{3}{4}$" and reamed $\frac{15}{16}$"	66 700 "	6.03 "	Cracked at hole at upper edge of angle.
Holes drilled $\frac{15}{16}$"	68 600 "	6.40 "	" " " "

Tests of riveted joints have been made by subjecting specimens to rapid impact, supposed to produce strains above the elastic limit; but such tests are necessarily tedious, and no result worth describing has been attained. It is not necessary to summarize the results of the previous experiments on sheared edges or specimens with open holes, as shearing to the extent described is neither usual nor necessary, and the effects of punching should be considered on the riveted structure, or in the condition in which the material is put in service. In the riveted joints it will be observed that there is little difference resulting from the manner of perforation, when the plates are thin, the inferiority of punched as compared to reamed work becoming more marked as the plates become thicker. This is due partly to the least injury being done to the thin plates, and partly to the clamping action of the rivet heads hereafter described, a force which necessarily bears a greater ratio to the strength of a joint composed of thin plates than to one of thicker material.

For the thinnest plates there is no diminution in the strength of the punched as compared to the reamed joint; in fact, in summing up the average result, the advantage rests with the punched joints.

It may be observed here, that this is not found with imperfect or loosely driven rivets. In the ½-in. iron plates, the punched joints withstood 20% less strain than the average of reamed and drilled, while the ½-in. punched steel only fell about 6% below the punched and drilled. In the case of steel, however, the joint was made with a double row of rivets, whereas the iron was a single row, and the former resisted distortion from bending better than the latter case.

The ⅝-in. punched iron joints fell 13% below the reamed and drilled, and the ⅝-in. punched steel plates dropped 20% below the reamed and drilled. For the ¾-in. plates of both materials, no comparison can be made, as the rivets sheared in every case for reamed and drilled holes; but drilled steel plates exceeded the punched steel plates 70% without developing the full resistance of the plate. It is probable that for steel plates of good quality, and below 80 000 lbs. tensile strength, there is no material gain by drilling or reaming over punching rivet holes in plates ⅝ in. thick and less provided that rivets are solidly driven, or even in plates ½ in. thick if holes are not unusually close, and are not too near the edges. Above this thickness, there can be no doubt of the advantage of reaming punched holes. The simplicity, economy and rapidity of the punching process as compared to drilling, naturally commends it to both the manufacturer and the purchaser of structural material. With given manufacturing facilities as represented in shop area and capital invested in appliances, at least 10 times greater quantity of material can be prepared by punching than by drilling in the same time, and further improvements that may expedite production are as evident in the former as in the latter process. Estimates based on the expenditure of labor, and assuming that the cost of raw material was threefold, that of the further treatment of ordinary heavy girder work with punched holes, show approximately the following relations between costs of structural material, as differently prepared.

Material ready for shipment.	Relative cost of shop work.	Cost of material.	Total relative cost of work.
Punched work	1	3	4
Reamed work	1½	3	4½
Drilled work	3	3	6

This estimate, however, is not complete, insomuch as it does not consider the enlarged production from a given investment in plant for punching instead of drilling rivet holes. There is no evidence that material with drilled holes is superior to that with punched holes properly reamed, unless material is of excessive thickness, say, over $\frac{3}{4}$ in., or unless holes are excessively close together; and it is sometimes urged that there is no evidence of any physical inferiority of punched work as compared to reamed work, so long as strains are below the elastic limit, or until permanent deformation has begun; therefore, some engineers, rather than pay an increase of 10% for reamed work, prefer to put 10% increased material in punched work.

It is probable that the best results combined with least expenditure can be obtained by punching all holes where vital strains are not transferred by the rivets; and by reaming for important joints where strains on riveted joints are vital, or wherever perforation may reduce sections to a minimum, such as the suspension joints of floor girders, the intersections of web members with flanges in latticed girders, etc., and all holes that have to be riveted during erection of work. The reaming should be sufficient to thoroughly remove the material disturbed by punching; to accomplish this, it is best to enlarge punched holes at least $\frac{1}{8}$-in. diameter with the reamer.

Riveting.—It is the current practice to perforate holes $\frac{1}{16}$ in. larger than the rivet diameter. For work to be reamed, it is also a usual requirement to punch the holes from $\frac{1}{8}$ to $\frac{3}{16}$ in. less than the finished diameter, the holes being reamed to the proper size in unity, after the various parts are assembled.

It is also excellent practice, not generally insisted upon, to remove the sharp corner at both ends of the reamed holes, so that a fillet will be formed at the junction of the body and head of the finished rivets. Where holes are punched to full diameter, it is desirable that the mating holes in assembled parts should coincide so accurately that the rivets will enter freely without any forcing or drifting. In practice it is difficult to uniformly obtain such accuracy of punching; therefore some reaming is unavoidable. Hence, the best practice for punched work is to punch all holes a trifle small and ream all after assembling, the reamer being sufficiently in excess of the punch diameter to partly at least, smooth the surface of the hole. Reaming to this extent does not materially delay or increase the cost of construction, and when the

plates are not thick, say not exceeding ½ in., it is probable the results for ordinary riveted seams will compare favorably with drilled holes.

The rivets of either iron or mild steel should be heated to a bright red or yellow heat and subjected to a pressure of not less than 50 tons per square inch of sectional area.

For rivets of ordinary length, this pressure has been found sufficient to completely fill the hole. If, however, the holes and the rivets are exceptionally long, a greater pressure and a slower movement of the closing tool than is used for shorter rivets has been found advantageous in compelling the more sluggish flow of the metal throughout the longer hole. The upsetting action occurs first at the end of the rivet where the final head is being formed, the metal finally upsetting under the previously formed head of the rivet; consequently, any looseness of the rivets is more apt to occur at the end next the original head. To obviate this, it has been proposed to use straight rivet blanks, and form the heads simultaneously at both ends. It has been proved advantageous to make the rivet head elongated and containing an excess of metal, forcing this excess into the body of the rivet when closing.

Machines for closing rivets should not have a movement that terminates when the rivet is supposed to be completed, but should be capable of following the compressed material to finality. A class of machines, however, are in common use, in which the elasticity of the frame allows for inequalities, or variations in the quantity of material in the rivet. It is not usual in modern practice on structural work to use the plate-closing attachment on riveting machines, as in ordinary work no advantage has been found from its use; but if the assembled plates are exceptionally thick, or numerous, it is probable that the plate-closer does good service. It would be better in either case to allow the pressure to remain on the rivet until it had cooled sufficiently to resist any tendency of the joint to separate. Wherever hand riveting is unavoidable, the rivet should be driven by a heavy sledge, operating on the cupped tool, as by the use of light hammers the head may be completed before the body of the rivet fills the hole. Experiments for resistance of a joint with rivets closed under different pressures gave the following result.

FIG. 6.

Three specimens of 3 x 1 in. flats, secured by two ⅞-in. rivets in $\frac{15}{16}$-in. holes, compressed with pressures of 70 000, 83 000 and 110 000 lbs., respectively. The pieces were then pulled in the testing machine and extensions measured in the 9 ins. between the rivets, as follows:

TABLE No. 13.

Tension applied in pounds.	Extension in inches for joint compressed with—		
	70 000 pounds pressure.	83 000 pounds pressure.	110 000 pounds pressure.
35 000	.03	.02	.025
40 000	.19	.085	.115
45 000	.25	.18	.17
50 000	.33	.26	.22
Final pressures and extensions when rivets sheared..............	51 000 — .36	55 000 — .39	56 000 — .32

The following experiment illustrates the clamping action of the rivets. 6 x ⅜ ins. iron plates were perforated with six accurately reamed holes, one-half of the lot was riveted under machine pressure, as shown on the left; the remainder had straight pins driven into the holes, as shown to the right. Pulled in testing machine until plates ruptured.

FIG. 7.

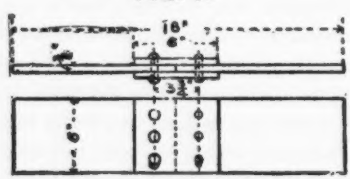


TABLE No. 14.

Diameter of holes.	Fastening.	Max. load in pounds.	Maximum load in pounds per square inch.		
			Net section of plate.	Rivet section.	Bearing area.
$\frac{11}{16}$"......	Rivets..........	81 950	52 000	36 900	64 100
	Pins............	77 200	49 300	34 770	60 400
$\frac{13}{16}$"......	Rivets..........	75 800	53 200	24 440	50 140
	Pins............	67 600	47 440	21 790	44 700
$\frac{15}{16}$"......	Rivets..........	73 200	57 240	17 700	42 000
	Pins............	66 500	52 000	16 070	38 150
$1\frac{1}{16}$"......	Rivets..........	72 650	64 350	13 680	36 760
	Pins............	57 250	50 700	10 760	28 970

For pin-connected structures, pin holes are necessarily bored and abutting surfaces faced, operations which are a subject of good workmanship and mechanical manipulation, which cannot be prejudicial to the material, and not considered in this paper.

Forging.—It is unnecessary to state that no welding should be allowed on any steel that enters into structures. The masses of greatest cross-section are used for pins. For the smaller diameters, say below 6 inches, they can be satisfactorily rolled; the larger sizes, involving insufficient reduction in the rolls, from ingots of greatest practicable section, should be forged, either under a heavy hammer, or preferably a press. The most powerful blooming mill will not close up a piped cavity in a large steel ingot that might disappear under a hammer or press of moderate capacity, and as such cavities will occasionally be found when not suspected, it is a safe practice to test excessively large pins by boring a hole lengthwise through the center; it is probable that this expense would be unnecessary on press-forged steel. Every precaution should be exercised to prevent the occurrence of such possible defects, in the event of wide tension bars of unusual thickness being required. Wherever practicable, it is desirable that the whole mass to be forged should be uniformly heated and no work performed on it after redness ceases to be visible, unless the piece is to be subsequently annealed. Pieces heated to a high temperature should be worked until sufficiently low in temperature.

It is a common belief that when metal remains heated above a certain temperature, without being compressed by manipulation, the resulting product has an open grain with inferior ductility. Numerous experiments have been made, but the demonstration is not very clear that the action is so injurious as has been claimed; that is, for the structural metal commonly known as mild or medium steel, and not containing elements to excess that might be especially detrimental to ductility under such circumstances. See some experiments in Tables Nos. 16 and 17; also, Nos. 7 and 8.

Enlarged ends on tension bars for screw-threads, eye-bars, etc., are formed by upsetting the material, and it is now abundantly demonstrated that with proper treatment and a sufficient increment of enlarged sectional area over the body of the bar, the result is entirely satisfactory. The upsetting process should be performed so that the properly heated metal is compelled to flow without folding or

lapping. If a fold occurs in upsetting, it may be cut out and the upsetting repeated; but no attempt should ever be made to weld the fissure formed by folding, as, however sound it may superficially appear, the result would be untrustworthy. The gripping tools used in upsetting should be so devised that they will not cut the surface nor impair the section of the gripped bar.

Annealing.—The object of annealing structural steel is for the purpose of securing a homogeneity of structure that is supposed to be impaired by unequal heating, or by the manipulation necessarily attendant on certain processes. The objects to be annealed should be heated throughout to a uniform temperature and uniformly cooled, and the process is not necessarily a softening one, as is inferred, when applied to high-grade steel for cutting tools, etc.

In referring to the subject of high temperatures in heated metals we are compelled, in the absence of convenient pyrometric devices, to use somewhat indefinite terms indicated by color. These terms have to be applied in the customary practical sense, allowing some latitude for different conditions and observers. For instance, a piece of metal heated visibly red in a dark shop or a gloomy atmosphere might appear to the same eye black under a brilliant light, and *vice versa.*

The proper temperature for, and results of, thorough annealing, depend on several conditions. The temperature to which the objects to be annealed should be heated depends on the existing amount of molecular disturbance that has to be neutralized. Thus, for material partially heated and forged or upset, a heat, bright red, or clean copper color, as viewed by ordinary shop light, and supposed to be about 1 200° Fahr., is found in daily practice to produce the desired results. Tests for commercial purpose are continually being made on eye-bars, annealed by heating to this extent without evidence of a higher temperature being requisite, although it is claimed by some that a lower temperature, say 1 000° Fahr., is sufficient. The temperature of 1 200° Fahr. is supposed to be about that now known as "recalescence" (probably dependent on the grade of the steel), and pieces heated not over this extent retain their form in the annealing furnace without the necessity of extremely careful and uniform support. When the physical change of material is more radical than aforesaid, as superficially occurs in shearing, punching, etc., it appears to be necessary to heat the material to a higher temperature than described, to entirely elimi-

nate the molecular disturbance. Compare tests Nos. 5, 10, 15 and 19 with 4, 9, 14 and 18, Table No. 8; also, tests 4 and 8 with 3 and 7, Table No. 7; also, see Table No. 17.

The physical effects of annealing, as indicated by tensile tests, depend on the grade of steel, or the amount of hardening elements associated with it; also, on the temperature to which the steel is raised, and the method or rate of cooling the heated material. Reference is made to some tests of annealed material on Tables Nos. 7 and 8, as well as those subjoined.

The physical effects of annealing medium-grade steel, as indicated by tensile test, are reported very differently by different observers, some claiming directly opposite results from others; and as the facts are reported by careful and impartial engineers, it is evident, when all the attendant conditions are considered, that the obtained results must vary, both in kind and degree. For the most recent statements on the subject, see those by Lewis and Dagron, Vol. XXVII, No. 4, *Transactions* Am. Soc. C. E., and Henning, Vol. XIII, Am. Soc. M. E.

The temperatures employed will vary from 1 000 to 1 500° Fahr., possibly even a wider range is used. In some cases the heated steel is withdrawn at full temperature from the furnace and allowed to cool in the atmosphere; in others, the mass is removed from the furnace, but covered under a muffle, to lessen the free radiation; or again, the charge is retained in the furnace, and the whole mass cooled with the furnace, and more slowly than by either of the other methods.

TABLE No. 15.

Four pieces cut from each of three steel bars and pulled as follows:

Test No.	Treatment of Material.		3 × ⅝"	3 × ¾"	3 × ⅞"
1	As rolled	T. S.	61 900	60 300	63 100
		E. L.	36 400	37 300	39 900
		St.	31	31	32
		Red	53	49	55
2	Heated red and covered in dry sand	T. S.	59 200	59 400	61 000
		E. L.	36 300	37 100	34 800
		St.	32	28	30
		Red	55	54	48
3	Heated red and cooled in atmosphere of 70°	T. S.	62 900	59 800	61 000
		E. L.	39 500	37 700	33 700
		St	32	31	30
		Red	58	48	53
4	Heated red and quenched in water of 70°	T. S.	73 400	75 000	
		E. L.	46 400	50 600	
		St	25	23	
		Red	51	47	

All fractures silky.

TABLE No. 16.

$\frac{7}{8}$-in. round Bessemer steel bar. Cut into 17 pieces and tested as follows:

Analyses:

Carbon, .09 Mang., .41 Silicon, .005 Phos., .115 Sulphur, .082

Test No.	Treatment.	T. S.	E. L.	St.	Red.	Nicked on one side, bent to given angle before separating. Degrees.
1	As Rolled: Average of two tests........	60 240	40 970	29	59	15
2	Heated red and covered in a box of pulverized charcoal. Average of two tests	59 860	40 300	31.5	66	12
3	Heated red and cooled in a closed box..	59 900	41 140	30.5	68.8	
4	Heated red and covered in dry sand......	61 300	39 400	29	63	24
5	Heated red and cooled in atmosphere about 60°. Average of two tests... ..	61 100	41 600	31	61	48
6	Heated red and cooled in sperm oil 44° Fahr..................................	65 840	46 470	27.5	54.5	
7	Heated red and cooled in water of 70° Fahr..................................	73 900	47 200	19	51	
8	Heated yellow and cooled in same water	77 300	47 300	18	48	17
9	Heated yellow and cooled in air of 60° Fahr. Average of two tests	62 300	42 400	29.5	65	57
10	Yellow heat maintained for 15 minutes and cooled in air.....................	63 500	42 700	24	65	30
11	Yellow heat maintained for 30 minutes and cooled in air.....................	62 300	41 100	25	61	54
12	Heated yellow, forged down ½-in. diameter, finishing at red heat. Average of two tests......................	61 600	45 100	22.6	68	

The yellow temperature was a bright, scale-forming heat as high as would be taken for forging. All fractures were silky, with the characteristic coning of the broken ends.

All specimens bent 180° without fracture after treatment.

TABLE No. 17.

Annealing Tests on Steel Bars with Sheared Edges.

A 4 × ½ in. steel flat bar was cut into 11 test strips, of which all but one had ½ in. sheared off each edge, leaving the specimens about 3 × ½ ins. Two of the latter had the edges planed and one left with sheared edges unannealed. The rest were heated and cooled as described.

Analyses :

Carbon, .34 Mang., .70 Silicon, .082 Phos., .065 Sulphur, .057

Test No.	Treatment.	T S.	E. L.	St.	Red.	Fracture.
1	Bar as rolled	79 500	40 500	27.0	48.5	S. A.
2	One-eighth in. planed off the sheared edges	79 370	40 100	25.0	43.0	"
3	One-sixteenth in. planed off the sheared edges	80 130	40 250	26.0	44.3	S. H. C.
4	Sheared edges unannealed		Record	lost		
5	Heated red and cooled in quiet atmosphere of 55° Fahr	78 700	37 910	19.4	51.4	S. A.
6	Heated red and cooled slowly in annealing box	72 150	43 750	25.3	36.0	S. H. C.
7	Red heat retained for one-half hour; cooled in air 55° Fahr	75 800	39 560	20.0	53.0	"
8	Red heat retained for one hour; cooled as above	74 600	41 560	16.5	51.4	S. A.
9	Red heat retained for two hours; cooled as above	74 180	38 280	14.8	51.1	47% crystal. 53% S. C.
10	Heated yellow; cooled in quiet atmosphere of 55° Fahr	78 560	42 550	16.3	49.1	S. A.
11	Yellow heat maintained for one-half hour; cooled as before	78 100	42 210	23.0	47.4	S. C.

S. A. — Silky-angular. S. C. = Silky-cupped. S. H.-C. = Silky-halfcupped.

No. 6 was cooled from redness in a tight-cased annealing box used for tools, but not covered under any substance; took about four hours to cool. Nos. 7 and 8 were retained at red heat in a closed muffle. Nos. 10 and 11 kept at yellow heat in the flame of an arched coke fire. Specimens, as treated, all bent 180° around a 1¼-in. pin, without cracking, except No. 1, which opened slightly on outside. Nicked and bent, all showed fine close grain, particularly Nos. 5 and 6, which were almost silky.

Specimens of steel cut from the same bar exhibit such different physical characteristics after being subjected to various temperatures or rates of cooling, that a definite result cannot be expected from annealing a miscellaneous lot of material.

We may assume that if steel was heated to a higher temperature than that at which it left the rolls, or if it was cooled more rapidly during annealing than after rolling, it would then be harder after the former process than after the latter; that is, it would probably at tensile test show higher tenacity and lower ductility. Compare tests 9 to 11 with 1 to 5 on Table No. 16, and tests 5, 10, 15 and 19 with 1, 6, 11 and 16, Table No. 8; also, tests 10 and 11 with 1 to 3 of Table No. 17. Or the contrary effects would occur, if the temperatures or rates of cooling were reversed. Thick bars of large sectional area are usually finished hotter than smaller bars, and are not liable to be made hotter during annealing ; they would therefore be more liable to be softened by the annealing than smaller sections. This would be more evident the higher the percentage of carbon in the steel.

But, on the other hand, bars reduced to small section, and finished at a low temperature, usually yield a high elastic limit, as illustrated at tests No. 12, Table No. 16, and this high elastic limit will usually be reduced by annealing. So, in a general sense, a reduction of tensile strength, and increased ductility, may be expected when steel is very slowly cooled after the annealing heat, and the contrary when it is rapidly cooled.

The best general results from annealing will probably be obtained by introducing the material into a uniformly heated oven in which the temperature is not so high as to cause a possibility of cracking by sudden and unequal changing of temperature; then gradually raising the temperature of the material until it is uniformly about 1 200° Fahr.· then withdrawing the material after the temperature is somewhat reduced and cooling under shelter of a muffle, sufficient to prevent too free and unequal cooling on the one hand, or excessively slow cooling on the other.

The foregoing statements are made with considerable reservation, as accurate knowledge of the subject has yet to be obtained.

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A PROPOSED METHOD OF TESTING STRUCTURAL STEEL.

By ALFRED E. HUNT, M. Am. Soc. C. E.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The methods in vogue of testing structural steel, for its quality as well as for its adaptability for the purpose required, in commercial practice at the present time are briefly as follows:

First.—Tensile tests, in which the results compared in the crucial examination are the elastic limit and tensile strength per unit of area as well as the percentage of elongation in given lengths and percentage of reduction of area.

Second.—Bending tests of the metal, both hot and cold and under varying conditions, such as quenching after being raised in temperature to a red heat, etc.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

Third.—Drifting tests, or the enlarging of holes punched or drilled in the metal, by pressure or blows upon a hardened steel drift pin.

Fourth.—Drop tests, where specimens under given conditions of support are struck by blows of a falling weight.

Fifth.—Chemical analyses, where the amounts of the constituents imparting hardness, as well as those supposed to injure the metal by rendering it either cold or hot-short, are determined.

Some of the disadvantages of these methods of testing structural steel are: that due to the time required and expense occasioned, the tensile and chemical and in many instances the drop tests made are too few in number to discover and check a lack of homogeneity in the metal; also considerably varying results can be obtained by taking specimens from different parts of the ingot or other object to be tested, and in the case of tensile tests by varying the method of testing as to the speed, amount of impact, or the application of strains, or by pulling the specimens out of line.

A further serious disadvantage—not an inherent one, it is true, but still one which, in the writer's opinion, has grown into a grave trouble in the requirements of many specifications and in the general practice of the interpretation of specifications for structural steel of to-day—is the narrowing of the allowable limits of the results of the present system of testing to an extent that is unwise in choosing steel suitable for structural purposes, and which leads to an excessive exclusion of material. This state of affairs is not only unjust to the mills, but unsatisfactory to the shops or constructing concerns. Annoying and expensive delays are often caused by rejection of material which the mill people had confidently reckoned upon shipping at stipulated times in accordance with their promises, on account of its being just outside of the narrow limits of specifications. In many such cases there has been not the least doubt, in the mind of the inspector, the mill management, or the contractor who was to fabricate the material into finished shape, that the rejected steel would have answered equally as well for the purpose for which it had been designed as much of that which had been accepted and which had given test results within the specifications.

This state of affairs acts, in the long run, very prejudicially to the interests of the engineer who draws the specification, and sometimes actually to the quality of the metal entering into his structure; for it tends to lower the ideas of the subordinate officials and "practical

men" at both the mills and shops as to the utility of specifications and of the necessity of honestly complying with them, as well as to an idea that the engineer, the author of the specifications, does not know what material he actually wants. Added to this, not only does the rejected material cost money, but the losses resulting from delays caused by rejections are, in the long run, figured into the general cost of doing work, and are added to the estimates of costs on which bids for future orders are based. Hence the specifications under which many jobs of work are let, such as some general railroad specifications, often cause considerably higher prices to be charged and paid for, as a result of the narrow limits of the specifications, as determined by previous experience with them.

Again, bending, drifting and similar tests of ductility do not give results, in numerical quantities, convenient for reference, comparison and record, or for exact stipulation of requirements in specifications.

The method of testing which the writer proposes consists in punching or otherwise shearing, cutting or drifting pieces of a given thickness of metal, and comparing the "force" required in this work with that required to treat standard pieces in a similar manner. The comparison can be similarly made with the "work" done, or factors of the work exerted therein at different stages of the punching, cutting or drifting operations, with results obtained in treating standard pieces in a similar manner.

The term "work" is not necessarily used in its strictly scientific definition, but is used to denote the product or results of two or all of the following three factors, of which one is the force necessary to punch a hole of given size, cut a given indenture, or drift a given hole to enlarge it a given amount; the second is the space through which the force moves its point of application during the act of punching, cutting or drifting, and the third is the time during which the force acts in the cutting, punching or drifting. In the practice of the method also, a combination of the first of these factors (the force) with the second or third, is often used; and, in fact, it is a combination of the force with the space through which the force moves its point of application that the author has, so far as his experience has gone, proven to be the best and most accurate way of using it.

The most convenient way to measure these factors of the "work" done, the writer has found to be by graphical representations upon

plotting paper, where the ordinates represent the force in pounds and the abscissæ represent the increments of space through which the force moves its point of application in punching, cutting or drifting; or by graphical cards in which the ordinates represent the force in pounds and the abscissæ the increments of time during which the force is acting. Of course, in both of these species of curves, the indications of the abscissæ and ordinates may be reversed, so that the abscissæ will indicate the force in pounds and the other factor of the work shall be indicated by the ordinates.

In order to produce these graphical curves, a mechanism is employed in which a sheet of ordinary section paper is placed upon a movable tablet or cylinder actuated by clockwork or other means of imparting a regular motion thereto, in the case of time being a factor of the work measured; or by some connection with the tool or some part of the mechanism which moves with the tool, in the case of the space through which the force acts being the other factor of the work employed. The pencil or stylus draws the curve, and bears upon the paper which is actuated either by a spring gauge or a measuring device constructed to connect with the punching, cutting or drifting mechanism, so that the pencil or stylus is moved in a direction transverse to the motion of the paper and a distance proportional to the pressure exerted in acting on the metal. Such methods of recording are familiar to engineers and need no further description.

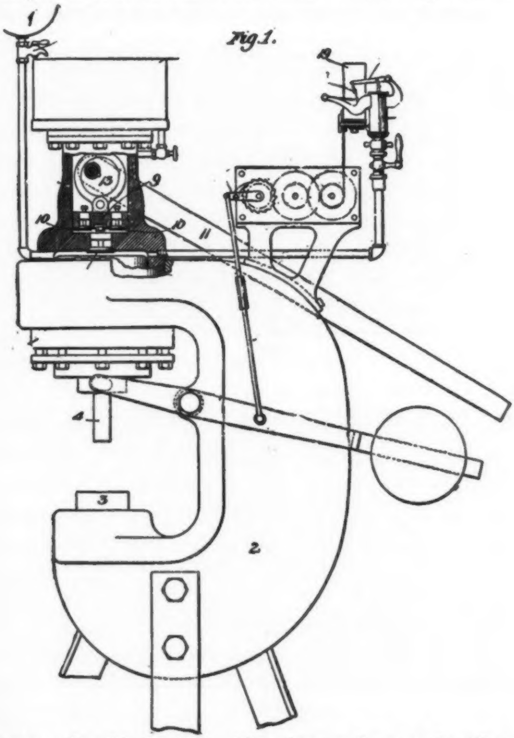
In punching, cutting or drifting by this method of testing, specimens of hard steel, *i. e.*, steel deficient in ductility, will yield very slight indications of being acted upon by the working tool, up to a much higher pressure than that required for such indication in treating specimens of softer or more ductile steel.

If curves be plotted or drawn in which, as above described, the ordinates indicate the force applied and the abscissæ the amount of cutting or the time of operation of the tool, the tool will be seen to have produced much less identation in the metal under the lower loads with hard than with soft steel, and, in the case of the hard metal, the curve will much more closely approximate the perpendicular or ordinate than with the soft metal.

Where the mechanism is so arranged as to plot a closed diagram, with the ordinates indicating the force applied and the abscissæ indicating the space through which the force is applied or the time during which

it acts, the upright lines of such diagrams in the case of the less ductile steel will be much more nearly perpendicular and parallel to each other than in diagrams obtained in testing softer specimens; they will also be higher because of the greater force required to act thus upon the metal. In a general way, also, the areas enclosed by the curves of such hard pieces of steel will be less than with soft specimens.

Fig. 1.



The reason for this is, that with softer and more ductile steel the indenting work of the tool is more uniform, beginning with the exertion of a lower force, and increasing gradually as the force applied increases; but with harder and less ductile steel, comparatively little action is produced by the tool until the pressure reaches a high point, when, with much greater abruptness, the punching or cutting tool pierces the metal.

By reference to Fig. 1, an apparatus is shown for the general pur-

pose of carrying on this method of testing. The apparatus consists of an hydraulic punch, having a main frame, marked "2"; a die or anvil for the punch, marked "3," on which the specimen to be punched is placed; the punch, marked "4," which is at the end of the hydraulic piston, marked "9"; the valves of which are marked "10"; the lever actuating the punch is marked "11"; the mercury gauge is shown only in quarter outline, and is marked "1." The connection with the indi-

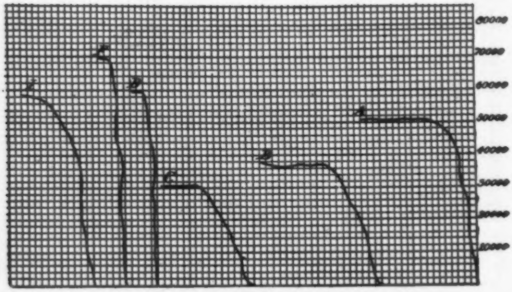


Fig. 2.

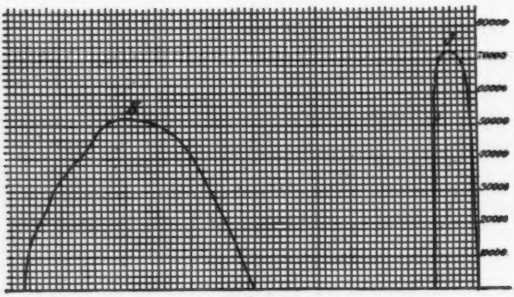


Fig. 3.

cator of the apparatus as used, preferably when steam is used in the punching cylinder, is evident by inspection of the drawing. The drum upon which the pencil works is marked "19."

Figs. 2 and 3 show copies of forms of curves upon specimens of $\frac{7}{16}$ in. thick steel, with the exception of sample "*C*," which was $\frac{5}{16}$ in. thick; the test curves, marked "*A*," "*B*" and "*C*," are of soft steel; "*D*," "*F*" and "*I*" are harder grades of steel; "*C*" is of the softest

basic steel, about 46 000 lbs. tensile strength per square inch; "*B*" of 50 000 lbs. tensile strength, and "*A*" of 69 000 lbs.; "*D*" is of 78 000 lbs. tensile strength steel; "*F*" of 85 000 lbs. tensile strength, and "I" of 75 000 lbs. tensile strength. In Fig. 3, the pencil was controlled by a spring, forming re-current curves; specimen "*J*" being of 78 000 lbs. tensile strength with 14% elongation in 8 ins., sample "*K*" being 65 000 lbs. tensile strength with 24% elongation.

By this method, tests can readily be made upon crop ends of pieces rolled from each ingot of steel used in any given lot of material; or, if necessary, pieces can be tested from crop ends taken from each end of large plates or bars, or from the bars and plates themselves. This ease of procuring samples and making the tests, and the absence of any large special expense therein, constitute a marked practical advantage for this method of testing.

In fact, it will be perfectly practicable to equip the punches used at bridge and boiler shops in actual practice, with some device for measuring the force or work done in punching; and by the aid of graphical devices, a record can be kept of the characteristics of every piece of metal punched that goes into any structure. In this way, it is the writer's judgment, that a more accurate and satisfactory system of testing can be carried on than is possible with methods in general use at present.

It is not to be inferred by this that the need of careful inspection at the mills will be done away with by the adoption of this method of testing; on the contrary, with the general adoption of steel to replace wrought iron in structures, there is, and probably will remain, a constant necessity for careful supervision by unprejudiced and skillful inspectors employed by and in the interests of the purchaser and not of the mills themselves, in order to insure suitable material, and this, too, at the largest and best appointed and managed steel mills of the country, as well as the less experienced and smaller plants. This opinion is expressed after an extended experience with the methods, shop practice and character of the material turned out at most all of the structural steel works of the country.

The characteristics of the metal actually developed by this method of testing are:

1. The ductility of the metal as compared with its tensile and shearing strength.

(*a*) The results of experiments of Appendix A show that with soft, ductile structural steel, with from 50 000 to 70 000 lbs. per square inch tensile strength, the shearing strength of the metal is about 75% of the tensile strength for single shear and about 73% for double shear.

(*b*) In punching tests, the product of the circumference of the punch by the thickness of the section is the area subject to the shearing action of the punch, at least up to $\frac{5}{8}$ in. thick sections. Using this area as a divisor and the actual force applied in pounds to punch the specimen as a dividend, will give as a quotient, with approximate accuracy, the shearing strength per square inch of the specimen.

The experiments described in Appendix B show that with soft, ductile structural steel of from 50 000 to 70 000 lbs. per square inch tensile strength, by using the formula $0.75\ U = S = \frac{P}{c \times t}$ where $U =$ ultimate tensile strength per square inch, $S =$ shearing strength per square inch, $P =$ pressure applied in pounds to punch the specimen, $c =$ circumference of the punch, and $t =$ thickness of the specimens, both the tensile and shearing strength are obtained within a reasonable limit by this method of testing.

(*c*) The experiments of Appendix C show that with very strong but ductile steel, of high tensile strength and large elongation, the formula given in paragraph (*b*) does not apply, as the shearing strength is not over 70%, and in some cases not over 60%, of the tensile strength.

(*d*) The experiments of Appendix D show that with hard and brittle steel with low ductility, the shearing strength more nearly approaches the tensile strength, and in the very hard steel exceeds the tensile strength, so that in these cases the formula given in paragraph (*b*) does not apply.

(*e*) The experiments of Appendix E show that with weak and rotten steel of low tensile strength and ductility the relation of shearing to tensile strength is not uniform, and that when the force applied to make the punching test is either abnormally low or high, or irregular, there is cause for further investigation of the metal.

(*f*) The experiments of Appendix F show that when in punching tests the thickness of the specimen is over $\frac{5}{8}$ in., with soft ductile steel, the effect of crushing instead of shearing is seen on the last or lower portion of the metal of both the punchings and of the walls of the steel in which the holes are punched, and that this factor is liable to

give irregular and misleading results as to quality. In these cases, a double set of punches, working against or into each other, will perhaps correct the trouble.

(*g*) The experiments of Appendix G show that the action of speed in punching does not modify the results to any considerable extent, especially where reasonable care is taken to have the testing conducted under uniform conditions in this respect.

(*h*) The experiments of Appendix H show that variations in power required in punching, due to the location of the punched holes and their environment, while being considerable, as shown by the tables, are nothing like as great as those occasioned by difference in quality of the metal. No marked error need occur in this method of testing, due to the very slight differences in the locations of the centers of the punched holes as regards the edge of the plate or the location of adjoining holes.

2. Experiments show that a method of selecting good structural steel, and discarding that which is unsuitable, can be devised by means of this method of testing its quality.

From the record of the experiments given (and in accordance with the writer's experience), it will be seen that good steel within the limit of 55 000 to 65 000 lbs. tensile strength per square inch, with an elongation of over 23% in 8 ins., a percentage of reduction of area of over 45%, and which pulls apart in tensile tests with a silky fracture, will require for $\frac{3}{4}$-in. punched holes (with centers $1\frac{1}{2}$ ins. from the edge of the specimen, when the specimen is punched in between 30 and 60 seconds time by a force applied gradually with a punch having $\frac{1}{8}$ in. clearance), a force proportioned to the thickness of the plate or bar, as follows:

Thickness.							
$\frac{3}{16}$ in.	section,	between	20 000	and	24 000	lbs. pressure.
$\frac{1}{4}$ "	"	"	25 000	"	30 000	"
$\frac{5}{16}$ "	"	"	33 000	"	40 000	"
$\frac{3}{8}$ "	"	"	40 000	"	46 000	"
$\frac{7}{16}$ "	"	"	48 000	"	55 000	"
$\frac{1}{2}$ "	"	"	56 000	"	63 000	"
$\frac{9}{16}$ "	"	"	65 000	"	73 000	"
$\frac{5}{8}$ "	"	"	73 000	"	80 000	"
$\frac{11}{16}$ "	"	"	80 000	"	88 000	"
$\frac{3}{4}$ "	"	"	85 000	"	95 000	"

Similarly, the work done in punching a ¾-in. hole, under similar conditions to those stated above, can be measured with various thickness of section of structural steel, and the specifications may require that it shall be at least equal to the minimum amount in the following table, where the force used as one factor in obtaining the work shall be, as a minimum, in accordance with the results given in the corresponding column:

	Minimum work in inch pounds must be	Where the force applied shall be at least
¼-in. section	3 125 lbs.	25 000 lbs.
5/16 " "	8 250 "	33 000 "
⅜ " "	10 000 "	40 000 "
7/16 " "	12 000 "	48 000 "
½ " "	14 500 "	56 000 "
9/16 " "	17 500 "	65 000 "
⅝ " "	19 000 "	73 000 "
11/16 " "	23 000 "	80 000 "
¾ " "	25 000 "	85 000 "

In another way, the work done in punching ¾-in. holes, under conditions similar to those given before, can be used as a means of specifying suitable structural steel, as shown by the graphical methods of representing the work done in punching in Fig. 3; by stipulating that under given conditions the work done, as measured by the area of cards produced under given specified conditions for each given thickness, shall have a minimum area in square inches equal to given amounts when the vertical height of the figures produced in measuring the work are no more than given amounts.

The writer has no doubt but that other and perhaps better methods will be devised for measuring the force or work applied in punching, cutting, indenting, or drifting the samples to be tested, and undoubtedly the limits advised in this paper for the requirements for specification will have to be revised as more experience is gained and more workers give their attention to the problems involved. The writer by no means wishes to claim that either perfection or the most accurate results have been arrived at in the matter of devising the best methods of applying this suggested new method of testing; on the contrary, better quick-acting machines, where the friction has been balanced or reduced to a minimum by special mechanism, and where new means

entirely may be employed to measure and record the results as well as to perform the several operations will undoubtedly be invented and adopted, should the method become of general use; and, indeed, while the results given in the appendices following this paper are by no means all the results in each line which have been made, they have been chosen as typical results of the entire series. At the same time the writer freely acknowledges that it will take a large number of tests and more workers in the field to give a sufficient amount of data upon which to generalize or to give results which can be safely recommended for specifications upon which important work is based, in the selection of steel for engineering purposes.

The writer's only claim is, that the general principles involved in this proposed method of testing are of more quick application than any other, and indicate and measure in perhaps a better way the qualities in structural steel that are desirable, as well as the undesirable attributes that the material may have which would make it unsuitable to be used for its designed purpose.

The writer does not claim that by the use of the proposed formula the method will give in all cases the tensile strength of the metal, but rather that it suggests a method of testing for that combination of strength and ductility desirable in structural steel. It does not, for instance, necessarily distinguish steel of over 65 000 lbs. from that of a higher tensile strength unless the ductility is correspondingly low. Steel of 70 000 lbs. tensile strength, with 27% elongation in 8 ins., might be accepted by the method of testing suggested, in the place of a maximum 65 000-lb. steel of some specifications, on account of the exceedingly good ductility of the specimen referred to; though such a steel could not be accepted under this method of testing when the work is used as the crucial test, and the stipulation is made that the work shall be at least a minimum amount, the force as one factor of the work not being over a given stipulated amount. But steel with 70 000 lbs. tensile strength with only 18% elongation in 8 ins. would be rejected, as shown by comparing the demands of the foregoing tables for proposed specifications for structural material, with the results from such steel as shown in the table of Appendix D.

This, the writer believes, is as it should be. A higher tensile strength steel, if accompanied with good ductility, as measured by stretch and reduction in tensile tests, should be accepted and not re-

jected, and the fact that this method of testing would include such steel is, in the writer's judgment, a point in favor of this method of testing.

Again, where the section is over $\frac{5}{8}$ in. in thickness, the crushing strength seems to be exceeded in the bottom portion of the punched metal, and the walls of both the hole and punching show markedly the line of demarcation between the sheared and the crushed surfaces of the metal. The force applied in punching seems to vary much more with steel of over $\frac{5}{8}$ in. thickness for varying factors of speed of the punching operation, character of the punch, and similar occasions for the variance of the results of the punching test; and the author does not claim from his experience that the same degree of accuracy can be obtained by this method of testing sections of over $\frac{5}{8}$ in. thickness as with thinner sections with the forms of apparatus already devised.

With the results given in Appendix G, it is shown that the speed with which the punching operation is done has only a comparatively slight influence upon the results. The force required to punch a given-sized hole through a given thickness of the same steel being a few thousand pounds more when the force is applied upon the punch quickly than when the force is applied gradually.

This variation, however, is not more than 2 000, or at most 3 000, lbs., with material up to $\frac{3}{8}$ in. thickness, and is no more than 5 000 for steel of $\frac{5}{8}$ in. thickness. These differences are well within the variance that should be allowed for good material, and, as our experience has shown, are nothing like the differences shown by the methods of testing between good, soft, ductile steel and hard or brittle steel.

The results as given in the tables of Appendices B, C and G show the difference between punching $\frac{3}{4}$ and $\frac{7}{8}$ in. diameter holes through different thicknesses of steel, and the results given in Appendix H show that where the location of the center of the punch varies in distance from the sheared or rolled edge of the steel it gives comparatively small variations in results. This table indicates that with ordinary care, precaution being taken to have the tools uniform in character and the methods of working reasonably similar, no wide variance or discrepancy of results will be encountered.

The same remark also applies to the method of dressing or arming the cutting edge and end of the punching or cutting tools. Widely varying ways of doing this will produce marked differences in the force

applied or work done in cutting or punching, through equivalent sections of the same steel. At the same time the differences due to these varying conditions are not so marked nor the method of testing so sensitive as to render the results untrustworthy when ordinary precautions necessary to accuracy with any method of testing are observed.

An advantage of the system is that it will always be perfectly practicable to keep, at places where tests are made, standard specimens of the thicknesses generally worked upon, which have been tested by other machines and under other conditions, and of which full records of results are ready for comparison; and at any time questions as to the apparatus in use being out of order or giving discordant results can be readily proven by making tests with the standard specimens to check the working of the apparatus.

When the necessary precautions that have been explained in this paper have been taken, it is the writer's judgment that this system of testing the quality of steel can be safely and conveniently used for structural purposes, and that it is sensitive enough and will exclude all classes of bad steel, and that which is unsuitable. It will, of course, take a large amount of testing and experience to develop all the facts regarding this. In a general way, however, the writer believes that, especially where specifications for structural steel are drawn requiring a minimum work where the actual force applied as one of the factors of the work is within given limits for each varying thickness of section, the results obtained by the method can be safely relied upon to reject, not only steel that will be too hard or too soft, but also that which will be too brittle or too weak, or that which has been burned, or steel that has not had a sufficient amount of "work" —in short, that it will reject metal that has any of the injurious qualities that steel is ordinarily rejected for, as regards its physical properties.

APPENDIX A.

Determination of Relation of Shearing to Tensile Strength.

Samples of $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$ and $\frac{7}{8}$ in. diameter round rods of soft steel were taken by the writer for experiments, care being taken in each instance to know the rods were each from homogeneous and uniform melts of steel that had previously been ascertained by frequent tests to be of good representative quality of that used in ordinary structural work, most of it being of a character used in the fabrication of rivets.

One or more portions of each rod were pulled apart in the 100 000-lb. Olsen testing machine of the Pittsburgh Testing Laboratory, and the ordinary tensile test results obtained are recorded in Table A of this appendix.

Adjoining portions of the same rods were sheared apart, either in single or double shear, in an apparatus in use by the writer at the Pittsburgh Testing Laboratory, and which is shown in Figs. 5, 6, 7 and 8. The opposite ends of the apparatus were, in most instances, held between the upper fixed and lower movable cross-heads of the Olsen testing machine of the Pittsburgh Testing Laboratory, although corroborative check results were obtained by use of the same apparatus attached to the heads of an 100 000-lb. Emery machine.

Single Shear

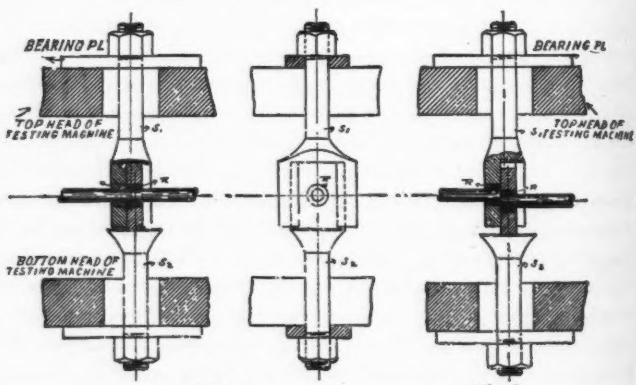


Fig. 5. Fig. 6.

The bearings or cutting edges of the shearing apparatus are rings R of Figs. 5, 6, 7 and 8 and are of specially prepared hard tool steel. Concordant, and the writer believes accurate, results were obtained in all the tests recorded in Table A, great care being taken to insure the specimens being sheared directly in line without unnecessary bending moments, and with precautions to keep friction at a minimum.

The results indicate that somewhat greater shearing strength is shown in single than in double shear with the method of testing adopted. An average of 16 results of specimens Nos. 3 to 18 inclusive, give the shearing strength in single shear as 75.46% of the

ultimate tensile strength, and only 73.56% in double shear. This is probably due to increased bending moments in the case of the specimens subject to double shear. Still, as the rods very closely filled the holes in the cutting rings in each instance, and the distance between shearing planes was 1 in., the conditions were very similar to the strains of double shear produced on rivets in actual practice.

The results, as a whole, show that the usual stipulations in engineering specifications, and the practice of allowing a unit strain in structural steel subject to shearing stress of 80% of that allowed in tension, is probably too liberal, and that it should be reduced to about 70% in metal subject to double shear, and not over 75% in that subject to single shear.

Double Shear

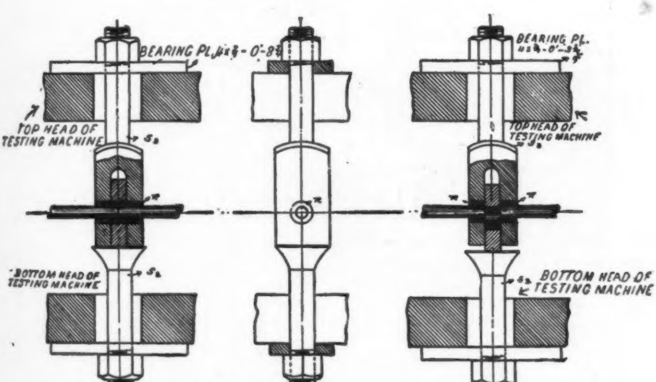


Fig. 7. Fig. 8.

Unfortunately, the literature of the relation of shearing to tensile strength is very limited, and the exact relations under different conditions have not yet been thoroughly worked up, so far as the writer can find in the various works on "Mechanics and Strength of Materials," which he has consulted. Nearly all of the works seem to agree that the shearing strength is 80% of the tensile, but very few results of actual experiments are given to substantiate these figures.

Thomas Box, in his work, deduces his values of the pitch of rivets by considering the shearing strength of the rivet per square inch as equal to 75% of the tensile strength of the plate per square inch.

Lanza, in his admirable work on "Applied Mechanics," paragraph 229, quotes the shearing strength of wrought iron and steel, as deduced from an experiment on torsional strength as: "Found to be about equal to the tensile strength. When deduced from experiments on riveted joints, it is found to be about three-quarters or four-fifths of the tensile strength."*

APPENDIX B.

A punching apparatus was used for the major portion of the tests given in Table B, and, in fact, was used in the punching results of the other tables of Appendices B, C, D, E, F, G and H as shown in Fig. 4.

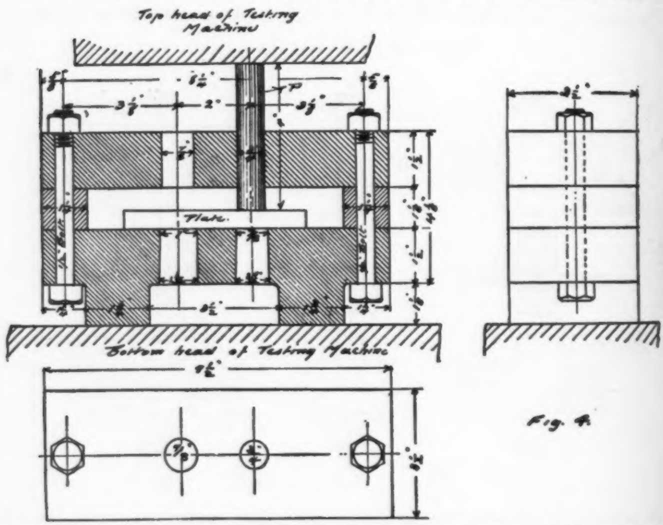


Fig. 4.

It consists of two plates of steel 1¼ ins. thick, which are held apart by 1⅛-in. blocks and bolted securely together with two ½-in. bolts at either end. The length of the apparatus is 9½ ins., the base plate having 1¼-in. projections upon which the apparatus rests. The plates are pierced with two holes for a ¾-in. punch in one instance, and a ⅞-in. punch in the other. The diameter of the lower dies is from 1 to $1\frac{1}{32}$ ins. for the ⅞-in. punch, and from ⅞ to $\frac{29}{32}$ in. for the ¾-in. punch.

* Very valuable data upon the shearing strength of steel has been lately published in the *American Engineer and Contract Journal*, by Mr. H. V. Loss; the writer having gone into the subject of shearing strength very fully.

TABLE A.

1	2	3	4	5	6	7	8	9	10	11	12	13
			TENSILE TEST.				SHEARING TEST.					
Specimen Number.	Description.	Diameter.	Elastic limit per square inch.	Ultimate strength per square inch.	Elongation in 8 ins. Percent.	Reduction of area. Percent.	Pounds actual exerted in single shear.	Pounds actual exerted in double shear.	Pounds per square inch exerted in single shear.	Pounds per square inch exerted in double shear.	Percent. of single shear to tensile strength.	Percent. of double shear to tensile strength.
1a	⅝" rod.	0.625	...	57 910	...	57.62	...	...	44 330	...	76.55	
1b	"	0.625	...	57 910	...	57.62	...	...	45 310	...	78.24	
2a	"	0.625	...	56 780	...	62.17	...	...	44 000	...	77.50	
2b	"	0.625	...	56 780	...	62.17	...	...	43 840	...	77.21	
3	⅞" rod.	0.858	43 590	61 400	30.50	59 52	27 100	52 250	46 870	45 180	76.34	73.60
4	"	0.857	43 250	58 770	31.25	60.30	26 900	51 450	46 640	44 600	79.33	75.90
5	"	0.860	42 520	60 170	30.00	60.00	26 700	52 000	45 960	44 760	76.38	74.39
6	"	0.855	42 240	60 970	30.00	60.84	26 200	51 600	45 640	44 950	74.86	73.56
7	¾" rod.	0.745	44 970	66 300	29.25	51.46	20 450	42 350	46 910	48 580	77.75	73.28
8	"	0.745	44 960	66 070	25.00	57.98	20 200	42 250	46 340	48 410	70.15	73.26
9	"	0.743	42 900	61 810	27.75	58.44	20 000	39 200	46 130	45 200	74.68	73.13
10	"	0.756	42 990	61 700	29.50	61.35	21 550	41 700	48 010	46 450	77.81	75.94
11	⅝" rod.	0.642	42 010	60 550	27.50	63.11	14 700	31 100	45 410	48 040	75.00	79.35
12	"	0.642	42 010	60 860	29.50	62.52	14 100	30 150	43 560	46 570	71.58	76.52
13	"	0.634	43 390	56 700	22.50	59.20	14 700	27 450	46 560	43 470	82.12	77.55
14	"	0.634	40 220	56 060	28.75	58.18	14 650	27 650	46 400	43 790	82.76	78.11
15	½" rod.	0.510	48 950	65 100	22.00	44.78	9 700	17 550	47 470	42 950	72.92	65.98
16	"	0.509	46 680	64 870	27.00	42.21	9 400	17 750	46 190	43 620	71.21	67.24
17	¾" rod.	0.756	44 550	61 040	27.00	62.98	20 950	40 950	46 670	45 610	76.48	74.80
18	"	0.757	43 550	60 880	27.50	58.07	20 550	40 700	45 660	45 220	74.84	74.26
19	⅞" rivet.	0.875	...	...	...	...	27 200	...	45 230			
20	"	0.878	...	...	...	...	24 500	...	40 460			
21	"	0.865 S.S. 0.871 D.S.	...	...	...	...	26 100	53 200	44 410	44 640		
22	¾" rivet.	0.752	...	...	...	...	19 300	...	43 470			
23	"	0.764	...	...	...	...	19 000	...	41 450			
24	"	0.761	...	...	...	...	22 000	...	48 380			
25	"	0.767	...	...	...	...	20 800	...	45 020			
26	⅝" rivet.	0.637	...	...	...	...	14 650	...	45 960			
27	"	0.636	...	...	...	...	14 150	...	44 540			

As the apparatus is arranged in Fig. 4, the plate to be punched (marked "Plate") is placed in position and the ¾-in. punch is placed upon it, the whole apparatus setting upon the bottom plate of the testing machine, from which the pressure applied is transmitted through to the weighing apparatus of the machine, the top head of the machine pressing directly upon the top of the ¾-in. punch. The other general dimensions are shown by inspection of Fig. 4.

The power required in punching samples of good structural steel is shown in Table B of this appendix. The specimens were selected as those having a tensile strength of between 50 000 and 70 000 lbs. per square inch, with good ductility.

Punching tests were made from the same material, with both the ¾ and ⅞-in. punches in most instances. The power was applied and measured, in these tests of Table B, upon an Emery 100 000-lb. capacity testing machine in all cases, except samples marked "6," "8," and "9," in which the first and second results, marked "*a*" and "*b*," were measured on the Emery testing machine, and the third and fourth marked "*c*" and "*d*," on a 100 000-lb. Olsen testing machine of the Pittsburgh Testing Laboratory. The legend of this table and, indeed, of the following tables of the other appendices of this paper, is as follows:

U = ultimate tensile strength per square inch.

S = shearing strength per square inch, as obtained by getting 75% of the tensile strength.

P = pressure applied in pounds to punch the material.

c = average circumference of the punching.

t = thickness of the specimen punched.

The shearing strength per square inch is represented by the formula:

$$\frac{P}{c \times t}.$$

Due to the large clearance of the punching apparatus, the value of c, or the average circumference, was found to be very closely the same through the varying thicknesses of metal, and was taken for the ¾-in. punch to be 2.5133 ins.; and with the ⅞-in. punch, c, or the average circumference, was taken at 2.9217 ins.

By inspection of Table B, the increment due to increased thickness to produce the punchings is shown throughout to be more or less regular, although the increment varies more above the thickness

of $\frac{5}{8}$ in. than with thinner sections, as shown more clearly in Appendix F. The average increment of pressure is found to be, as an average of a large number of experiments, from 112 to 120 lbs. for each $\frac{1}{1000}$ in. added thickness for the $\frac{3}{4}$-in. diameter punchings, and from 133 to 137 lbs. similarly for the $\frac{7}{8}$ diameter punchings in ordinary cases of good steel.

Specimen No.	1 is	acid open hearth	steel.		Specimen No.	18 is	acid	Bessemer	steel.
"	2 "	" "	"		"	19 "	"	"	"
"	3 "	" Bessemer	"		"	20 "	"	"	"
"	4 "	basic open hearth	"		"	21 "	"	open hearth	"
"	5 "	acid Bessemer	"		"	22 "	"	Bessemer	"
"	6 "	basic open hearth	"		"	23 "	"	open hearth	"
"	7 "	" "	"		"	24 "	basic	"	"
"	8 "	" "	"		"	25 "	acid	"	"
"	9 "	" "	"		"	26 "	"	"	"
"	10 "	" "	"		"	27 "	basic	"	"
"	11 "	acid "	"		"	28 "	"	"	"
"	12 "	" "	"		"	29 "	"	"	"
"	13 "	" Bessemer	"		"	30 "	acid	"	"
"	14 "	basic open hearth	"		"	31 "	"	"	"
"	15 "	acid "	"		"	32 "	"	"	"
"	16 "	" "	"		"	33 "	basic	"	"
"	17 "	" Bessemer	"						

APPENDIX C.

Similar tests to those described in Appendix B were made by the writer upon similar samples of steel of extra purity and quality, and which have exhibited very high ductility as compared to the ultimate strength in tensile tests.

The same legend which has been used in Appendix B applies to this Appendix and its Table C.

The results of 12 tests upon six different samples give, as an average of the percentages of the shearing strength per square inch of the ultimate tensile strength, 67.63% for the steel punched with $\frac{3}{4}$-in. punch, and 67.74 % with the same steel punched with the $\frac{7}{8}$-in. punch.

All the specimens of steel of Table C were made by the acid open hearth process.

The results clearly show that with this class of steel the shearing strength per square inch, as determined by the formula $\frac{P}{c \times t}$, is a smaller percentage of the ultimate tensile strength, and the steel is not of so great comparative ductility, a state of affairs that by no means points necessarily to a poor quality of steel, and, in fact, in the par-

ticular steel under consideration, is an evidence of superior quality instead.

APPENDIX D.

Similar tests to those described in Appendices B and C were made by the writer upon samples of hard and brittle steels, most of which owed their hard and brittle qualities to high carbon or high phosphorus, or a combination of the two, or to large proportions of manganese probably not uniformly distributed through the metal.

The same legend which has been used in the previous Appendices B and C applies to this appendix and its Table D.

In the case of the hard and brittle steels, the results given in Table D show that the shearing strength approaches much more nearly the tensile strength than with softer and more ductile metal.

Specimens numbered 1 to 5 inclusive were of acid Bessemer steel. Specimen No. 6 was made by the basic Bessemer process ; and specimen No. 8 was crucible steel.

APPENDIX E.

Similar tests to those described in Appendices B, C, and D were made by the writer upon samples of steel which had proven weak and rotten in tensile tests.

The same legend which has been used in the previous Appendices B, C and D applies to this appendix and to Tables E1 and E2.

The proportion between the shearing strength as determined by the formula $\frac{P}{c \times t}$ and the ultimate tensile strength, varies greatly with this class of steel, due to the peculiar condition it may be left in. Some weak steel is superficially quite hard, while others are softer throughout than ordinary steel.

In almost all cases the pressure applied is less in punching with this class of steel than with good steel, though this is not, in fact, the case with the samples of weak steel chosen for this appendix.

In the case of the "burned" steel of ordinary grades, Table E2 shows an average loss of $2\frac{36}{100}\%$ for $\frac{3}{4}$-in. punching, and $1\frac{48}{100}\%$ with the $\frac{7}{8}$-in. punch, of the power used in punching the same metal before it was burned.

All the specimens of Table E2 were the same as previously reported

in Table B, the steel being purposely and markedly "burned" for the purpose of making these tests.

The writer's experience with testing this class of metal points to the necessity of the use of some method of measuring the work done in punching, as a crucial test by this method for pointing out weak and rotten steel, where the work done instead of the force alone is employed as the method of testing. It seems very easy to discriminate this class of poor steel, as the amount of work done is always markedly less in such cases than with good steel treated similarly.

In the case of specimens of Table E1, the steel had evidently never been properly refined, due in the case of specimens Nos. 4, 5, 6 and 7, made by the acid open hearth process, to a cold open hearth furnace, unskillful melting, failure of gas supply, or a similar cause. In the case of the acid Bessemer steel specimens Nos. 1 and 3, due to a bad pig-iron mixture working cold, a lack of wind pressure or similar cause.

In the cases of burned steel shown in Table E2, often such steel is rendered superficially hard and brittle, probably due to the absorption by the metal of considerable amounts of occluded gases at the high temperature it had been subjected to at the time it was burned. Most steels, however, show a less tensile strength and take less power to punch after being burned. In other words, these burned steels are weaker and are made rotten by burning, as shown by inspection of Table E2. In some cases, however, probably, as above explained, due to the occlusion and chemical combination of occluded gases, burned steel is rendered hard and brittle, although in such cases the writer's experience has been that the elastic limit of tensile specimens very closely approaches the ultimate strength, and by the burning operation the character of the steel is made to approach that of cast iron.

By inspection of the pressures applied upon the specimens of the steel, both before and after burning, a marked diminution of pressure will be noted in the burned specimens, and had the results been calculated upon the same thicknesses of metal, columns 12 to 17, inclusive, of Table E2 would have shown the same marked variances, so that in actual practice burned steel of any given section can be told ordinarily by the diminution in pressure required in punching. The burning operation in each case raised a heavy scale which was cleaned off before the specimens were punched in each case, and the calculations of the table were made upon the decreased sections of actual metal punched.

APPENDIX F.

Action of the Thickness of the Specimen in Punching.

The records of tests of steel of over $\frac{5}{8}$ in. thickness so far made by the writer have not given as uniform results as similar results of steel lower thickness.

There seems to be a crushing action upon the lower sections of the metal which seems to be plainly shown upon examination of both the walls of the punched holes and the punchings themselves.

The tests have also shown the general shop rule to be a good one, of never using a punch in steel of a thickness greater than the diameter of the punch. In several instances of punching up to $\frac{7}{8}$ and 1 in. thickness, the punches of $\frac{3}{4}$ in. diameter made of best steel failed, in most cases, by bending.

As a general rule, material thicker than $\frac{5}{8}$-in. requires a little lower pressure per square inch than thinner sections of the same steel, probably due partly to the crushing action of the lower part of the metal mentioned above, and partly to the fact that the thicker steel has not had proportionately so much work upon it in most cases, and is not so strong, either in tensile or shearing strength, as the thinner rolled material.

Specimens, the tests of which are tabulated in Table F as Nos. 1, 2, 10, 11, 13, are of acid Bessemer steel; Nos. 3, 5, 8 are of basic open hearth steel; and Nos. 4, 6, 7, 9, 12, 14 are acid open hearth steel.

APPENDIX G.

The Action of Speed of Punching in Modifying the Results in Punching Tests.

A considerable number of specimens of steel were taken which had been proven to be very homogeneous throughout, and on which a good many results of punching tests had been obtained. These were again tested and the power applied in punching both $\frac{3}{4}$ and $\frac{7}{8}$-in. holes was measured. The power was applied very gradually, from 1 to 10 minutes' time being occupied in some cases, and in others, on the same steel, performing the punching in from 10 to 60 seconds. This was done very accurately, with the aid of the rapid-working plunger of an

TABLE

Samples of Good Soft Steel of Average Quality between 50

1	2	3	4	5	6	7	8	9
			Tensile Tests.				Punching Tests.	
Specimen Number.	Description cut from—	Thickness of specimen.	Elastic limit per square inch.	Ultimate strength per square inch. *U*.	Elongation in 8 ins. Percent.	Reduction of area. Percent.	Pressure applied in pounds to punch $\frac{3}{4}$-in. diameter punch. *P*.	Pressure applied in pounds to punch $\frac{7}{8}$-in. diameter punch. *P*.
1 a	6$\frac{3}{4}$" x $\frac{3}{16}$" Pl.	0.185	48 360	65 720	20.00	57.04	21 600	25 200
1 b, c	"	"	"	"	"	"	"	"
2 a	2" x 2" x $\frac{3}{16}$" L.	0.187	46 200	66 200	21.30	58.10	23 500	27 500
2 b	"	"	"	"	"	"	"	"
3 a	3" x 3" x $\frac{1}{4}$" L.	0.245	41 770	61 590	25.00	51.90	28 300	31 800
3 b	"	"	"	"	"	"	"	32 200
4 a	15" x $\frac{1}{4}$" Pl.	0.256	42 200	63 500	25 80	56.30	29 800	33 500
4 b	"	"	"	"	"	"	"	"
5 a	3" x 3" x $\frac{5}{16}$" L.	0.310	38 900	60 970	25.00	53.80	37 000	41 300
5 b	"	"	"	"	"	"	36 800	"
6 a	62" x $\frac{5}{16}$" Pl. 136"	0.320	37 200	61 590	24.80	54.20	36 500	40 800
6 b	"	"	"	"	"	"	"	"
6 c	"	"	38 000	62 400	25.80	55.00	37 100	43 600
6 d	"	"	"	"	"	"	"	"
7 a	10$\frac{1}{2}$" x $\frac{3}{8}$" Pl.	0.365	38 630	58 370	25.00	62.50	45 700	46 800
7 b	"	"	"	"	"	"	44 000	48 900
8 a	10" x $\frac{3}{8}$" Pl.	0.365	41 960	67 170	26.25	51.47	46 100	53 800
8 b	"	"	"	"	"	"	45 800	53 000
8 c	"	"	42 500	68 000	26.80	50.90	"	53 900
8 d	"	"	"	"	"	"	"	"
9 a	10" x [illegible]" Pl.	0.364	39 060	64 240	26.25	50.62	46 600	52 400
9 b	"	"	"	"	"	"	46 300	52 100
9 c	"	"	38 200	63 500	26.00	51.30	46 000	52 000
9 d	"	"	"	"	"	"	46 100	51 800
10 a	10" x $\frac{3}{8}$" Pl.	0.370	32 100	50 800	29.80	72.10	39 800	45 100
10 b	"	"	"	"	"	"	40 200	45 300
11 a	"	0.360	42 820	70 790	23.75	51.70	48 100	54 500
11 b	"	"	"	"	"	"	"	54 800
12 a	25" x $\frac{7}{16}$" Pl.	0.430	40 350	61 910	28.00	53.80	50 200	58 300
12 b	"	"	"	"	"	"	51 600	58 400
13 a	4" x 4" x $\frac{7}{16}$" L.	0.438	42 000	63 500	24.60	50.30	54 000	62 100
13 b	"	"	"	"	"	"	53 800	61 800
14 a	20" x $\frac{1}{2}$" Pl.	0 500	39 360	61 990	26 00	52.30	60 300	66 900
14 b	"	"	"	"	"	"	59 400	68 100
15 a	16" x $\frac{1}{2}$" Pl	0.505	37 300	55 900	27.30	64.20	56 900	64 800
15 b	"	"	"	"	"	"	57 200	65 300
16 a	5" x 3$\frac{1}{2}$" x $\frac{1}{2}$" L.	0.536	39 210	59 900	26.20	58.30	62 000	70 100
16 b	"	"	"	"	"	"	62 100	69 400
17 a	6" x 6" x $\frac{9}{16}$" L.	0.580	39 480	62 380	26.25	55 30	70 000	79 000
17 b	"	"	"	"	"	"	69 000	78 300
18 a	6" x 6" x $\frac{9}{16}$" L.	0.555	38 710	60 910	25.00	54.40	67 100	76 400
18 b	"	"	"	"	"	"	65 700	76 100
19 a	18" x $\frac{9}{16}$" Pl.	0.560	36 430	63 290	28.50	59.93	61 000	71 400
19 b	"	"	"	"	"	"	62 000	71 500
20 a	5" x 5" x $\frac{5}{8}$" L.	0.600	39 440	62 380	25.00	50.70	74 000	83 300
20 b	"	"	"	"	"	"	74 300	83 200
21 a	10" x $\frac{5}{8}$" Pl.	0.620	43 000	69 500	23.80	48.60	75 900	84 600
21 b	"	"	"	"	"	"	75 400	86 200
22 a	6" x 6" x $\frac{11}{16}$" L.	0.670	40 700	61 100	23.75	56.20	86 000	93 100
22 b	"	"	"	"	"	"	85 500	93 700
23 a	18" x $\frac{11}{16}$" Pl.	0.690	37 500	56 200	24 80	53.90	80 500	89 100
23 b	"	"	"	"	"	"	80 200	89 000
24 a	4" x 4" x $\frac{3}{4}$" L.	0.725	33 330	60 160	28.75	54.90	82 000	97 300
24 b	"	"	"	"	"	"	83 800	96 700
25 a	10" x $\frac{3}{4}$" Pl.	0 755	37 090	63 300	30.00	62.00	83 000	92 000
25 b	"	"	"	"	"	"	83 000	99 000
26 a	10" x $\frac{13}{16}$" Pl	0.817	......	......	......	......	90 300	97 500
26 b	"	"	......	......	......	......	88 100	100 400
27 a	6" x 6" x $\frac{13}{16}$" L.	0.813	38 200	62 400	24.30	52.00	93 000	101 900
27 b	"	"	"	"	"	"	94 000	100 700
28 a	24" x $\frac{7}{8}$" Pl.	0.880	32 650	57 870	27.00	59.00	101 000	114 000
28 b	"	"	"	"	"	"	......	107 000
29 a	18" x $\frac{7}{8}$" Pl.	0 876	34 000	64 800	23.80	51.10	105 000	119 000
29 b	"	"	"	"	"	"	103 000	121 000
30 a	6" x 6" x $\frac{15}{16}$" L.	0.910	......	......	......	......	......	119 000
31 a	"	0.938	34 500	62 100	23.00	48.00	117 000	120 000
31 b	"	"	"	"	"	"	110 000	"
32 a	21" x 1" Pl.	1.010	38 270	56 320	30.50	53.30	......	121 000
32 b	"	"	"	"	"	"	......	"
33 a	15" x 1" Pl.	1.008	35 650	57 200	23.80	47.90	113 000	124 000
33 b	"	"	"	"	"	"	115 000	126 000

TABLE B.

TY BETWEEN 50 000 AND 70 000 LBS. TENSILE STRENGTH PER SQU

9	10	11	12	13
NG TESTS.	RESULTS OBTAINED BY CALCULATION.			
Pressure applied in pounds to punch $\frac{7}{8}$-in. diameter punch. P.	$\frac{P}{c \times t}$ with $\frac{3}{4}$-in. diameter punch. $c = 2.5133$.	$\frac{P}{c \times t}$ with $\frac{7}{8}$-in. diameter punch. $c = 2.9217$.	$S = 75\%$ of U	Percent. $\frac{P}{c \times}$ is to ultimat strength, $\frac{3}{4}$-i diameter pun
25 200	46 450	46 610	49 290	70.68
"	"	"	"	"
27 500	50 000	50 320	49 650	75.54
"	"	"	"	75.52
31 800	45 960	44 430	46 190	74 64
32 200	"	44 980	"	"
33 500	46 320	44 780	46 630	72.94
"	"	"	"	"
41 300	47 500	45 830	45 730	77.91
"	47 240	"	"	77.48
40 800	45 280	43 640	46 190	73.68
"	"	"	"	"
43 600	46 130	44 170	46 800	73.94
"	"	"	"	"
46 800	49 810	43 880	43 780	85.32
48 900	47 960	45 850	"	82.12
53 800	50 250	50 440	50 380	74.80
53 000	49 920	49 700	"	74.32
53 900	50 040	50 540	51 000	74.50
"	49 920	"	"	74.32
52 400	50 930	49 270	48 180	79.28
52 100	50 600	49 010	"	76.29
52 000	50 270	48 900	47 630	76.12
51 800	50 380	48 710	"	75.82
45 100	42 800	41 720	38 100	84.26
45 300	43 230	41 900	"	85.90
54 500	53 160	51 810	53 090	75.10
54 800	"	52 100	"	"
58 300	47 370	46 410	46 440	76.50
58 400	47 330	46 490	"	77.10
62 100	49 650	48 530	47 630	77.24
61 800	48 870	48 290	"	76.36
66 900	47 980	45 790	46 490	77.27
68 100	47 270	45 240	"	77.26
64 800	44 840	43 920	41 920	80.21
65 300	45 070	44 260	"	80.62
70 100	46 020	44 770	44 930	76,83
69 400	46 100	44 320	"	76.96
79 000	48 020	46 620	46 790	76.98
78 300	47 340	46 210	"	75.89
76 400	48 100	47 110	45 680	78.97
76 100	47 090	46 930	"	77.32
71 400	43 340	43 640	47 470	68.48
71 500	44 050	43 710	"	69.60
83 300	49 070	47 520	46 790	78.66
83 200	49 270	47 460	"	78.98
84 600	48 720	46 700	52 130	70.10
86 200	48 400	47 580	"	69.64
93 100	51 070	47 590	45 850	83 58
93 700	50 830	47 870	"	83.25
89 100	46 420	44 200	42 150	82 20
89 000	46 260	44 150	"	82.32
97 300	45 010	45 930	45 120	74.82
96 700	46 000	45 650	"	76 46
92 000	43 740	41 670	45 300	72 44
99 000	44 800	44 840	"	74.21
97 500	43 980	40 850	....	....
100 400	42 920	42 060	....	....
101 900	45 520	42 910	46 800	72.96
100 700	46 020	42 400	"	73.74
114 000	45 640	44 340	43 410	78.86
107 000	....	41 630	"	....
119 000	47 680	46 500	48 600	73.59
121 000	46 800	47 290	"	72.22
119 000	....	44 760	....	....
120 000	49 630	43 800	46 580	79.92
"	46660	"	"	75.14
121 000	....	41 010	42 240	....
"	....	"	"	....
124 000	44 620	43 110	42 900	78.01
126 000	45 410	42 780	"	79.38

…per Square Inch.

13	14	15	16	17
…culation.		Analyses of Steel.		
Percent, $\frac{P}{c \times t}$ is to ultimate strength, ¾-in. diameter punch.	Percent, $\frac{P}{c \times t}$ is to ultimate strength, ⅞-in. diameter punch.	Carbon. Percent.	Manganese. Percent.	Phosphorus. Percent.
70.68	70.92	0.12	0.50	0.064
"	"	"	"	"
75.54	76.10	0.22	0.51	0.021
75.52	"	"	"	"
74.64	82.74	0.11	0.46	0.086
"	73.04	"	"	"
72.94	70.52	0.24	0.44	0.018
"	"	"	"	"
77.91	75.16	0.10	0.46	0.084
77.48	"	"	"	"
73.68	70.86	0.25	0.48	0.023
"	"	"	"	"
73.94	70.78	"	"	"
"	"	"	"	"
85.32	75.16	0.15	0.45	0.012
82.12	78.54	"	"	"
74.80	75.10	0.24	0.45	0.028
74.32	73.99	"	"	"
74.50	75.24	"	"	"
74.32	"	"	"	"
79.28	76.70	0.27	0.42	0.017
76.29	76.24	"	"	"
76.12	77.00	"	"	"
75.82	76.70	"	"	"
84.26	82.10	0.13	0.29	0 018
85.90	82 48	"	"	"
75.10	73.21	0.19	0.49	0.071
"	73.60	"	"	"
76.50	74.98	0.15	0.33	0.074
77.10	75.09	"	"	"
77.24	76.43	0.14	0 43	0.081
76.36	76.05	"	"	"
77.27	73.88	0 21	0.42	0.011
77.26	73.99	"	"	"
80.21	78.56	0.10	0.36	0.073
80.62	79 17	"	"	"
76.83	74.74	0.12	0.37	0.062
76.96	73 99	"	"	"
76.98	74.74	0.15	0.54	0.097
75.89	74.08	"	"	"
78.97	77.34	0.13	0.32	0.103
77.32	77.06	"	"	"
68.48	68.95	0.16	"	0.089
69.60	69.06	"	"	"
78.66	76.18	0.10	0.50	"
78.98	76.10	"	"	"
70.10	67.20	0.18	0.39	0.077
69.64	68.46	"	"	"
83 58	77.81	0.16	0 69	0 105
83.25	78.34	"	"	"
82 20	78.65	0.17	0.49	0.082
82.32	78.56	"	"	"
74.81	76.34	0.15	0.45	0.009
76 46	75.88	"	"	"
72 44	69.00	0.13	0.58	0 060
74.24	74.25	"	"	"
......	......	"	0.53	0.077
......	......	"	"	"
72.96	68.76	0 19	0 37	0.028
73.74	67 95	"	"	"
78.86	76.62	0.25	0.51	0.009
......	71.94	"	"	"
73.59	71.76	0.27	0.37	0.021
72.22	72.90	"	"	"
......	......	0.11	0.53	0.092
79.92	70.54			
75.14	"			
......	72.82			
......	"			
78.01	73.62	0.23	0.39	0.025
79.38	74.79	"	"	"

TABLE C.

VERY PURE AND GOOD STEEL OF HIGH TENSILE ST

1	2	3	4	5	6	7	8	9
			TENSILE TEST.				PUNCHING TEST.	
Specimen Number.	Description cut from—	Thickness of specimen.	Elastic limit per square inch.	Ultimate strength per square inch.	Elongation in 8 ins. Percent.	Reduction of area. Percent.	Pressure applied in pounds to punch with ¾-in. punch.	Pressure a plied in pounds t punch wi ⅞-in. punch.
1a	10'' × ⅜'' Pl.	0.365	44 220	73 600	24.25	50.67	46 600	52 100
1b	"	"	"	"	"	"	46 600	53 000
2a	10'' × ⅜'' Pl.	0.360	40 820	70 790	25.75	51.77	48 100	54 900
2b	"	"	"	"	"	"	47 900	54 700
3a	10'' × ⅜'' Pl.	0.367	42 060	70 170	25.75	50.99	47 500	52 800
3b	"	"	"	"	"	"	46 800	52 900
4a	5'' × 3½'' × ½'' L.	0.536	41 300	70 200	27.30	54.60	62 100	71 800
4b	"	"	"	"	"	"	61 800	71 900
5a	5'' × ½'' bar.	0.505	47 900	82 400	25.10	52.25	64 900	73 400
5b	"	"	"	"	"	"	65 200	73 500
6a	6'' × 6'' × $\frac{9}{16}$'' L.	0.561	45 000	78 800	26 25	54.00	68 800	76 300
6b	"	"	"	"	"	"	69 000	76 800

* Average, 67.63 per cent.
† Average, 67.74 per cent.

E C.

TENSILE STRENGTH AND DUCTILITY.

	9	10	11	12	13	14	15	16
…CHING TEST.		RESULTS OBTAINED BY CALCULATION.				ANALYSES.		
…e ap- in …s to with …n. …h.	Pressure applied in pounds to punch with ⅞-in. punch.	$\frac{P}{c \times t}$ with ¾-in. diameter punch.	$\frac{P}{c \times t}$ with ⅞-in. diameter punch.	Percent. of $\frac{P}{c \times t}$ with ¾-in. diameter punch to ultimate strength.	Percent. of $\frac{P}{c \times t}$ with ⅞-in. diameter punch to ultimate strength.	Carbon. Percent.	Manganese. Percent.	Phosphorus. Percent.
…0	52 100	50 800	48 900	69.02	66.37	0.17	0.55	0.041
…0	53 000	50 800	49 750	69.02	67.53	"	"	"
…0	54 900	53 160	52 200	75.10	73.74	0.18	0.51	0.037
…0	54 700	52 940	52 000	74.78	73.45	"	"	"
…0	52 800	51 500	49 240	73.39	70.17	0.16	0.49	0.042
…0	52 900	50 740	49 340	72.31	70.32	"	"	"
…0	71 800	46 100	45 850	65.67	65.34	0.19	0.51	0.029
…0	71 900	45 870	45 920	65.34	65.41	"	"	"
…0	73 400	51 720	49 750	62.04	60.38	0.24	0.48	0.031
…0	73 500	51 360	49 810	62.33	60.45	"	"	"
…0	76 300	48 790	46 550	61.92	59.07	0.20	0.59	0.035
…0	76 800	48 940	46 850	*62.11	†59.45	"	"	"

s.
nt.

1
37
12
29
31
35

TABLE D.

Hard Brittle Steel.

1	2	3	4	5	6	7	8	9
			Tensile Test.				Punching Test.	
Specimen Number.	Description cut from—	Thickness of specimen.	Elastic limit per square inch.	Ultimate strength per square inch.	Elongation in 8 ins. Percent.	Reduction of area. Percent.	Pressure applied in pounds to punch with 3/4-in. punch.	Pressure applied in pounds to punch with 7/8-in. punch.
1a	10'' × 3/8'' Pl.	0.361	49 900	71 200	16.30	30.80	60 400	67 900
1b	"	"	"	"	"	"	61 000	68 300
2a	12'' × 3/8'' Pl.	0.369	55 100	74 100	13.20	21.10	64 200	71 800
2b	"	"	"	"	"	"	64 000	71 500
3a	4'' × 4'' × 7/16'' L.	0.435	48 200	82 200	8.10	15.10	80 300	87 100
3b	"	"	"	"	"	"	81 000	87 500
4a	6'' × 1/2'' Pl.	0.515	43 400	70 800	18.80	28.90	70 900	78 300
4b	"	"	"	"	"	"	73 000	80 100
5a	3 1/2'' × 3 1/2'' × 1/2'' L.	0.505	46 300	76 400	18.10	29.50	75 300	82 900
5b	"	"	"	"	"	"	77 000	84 500
6a	15'' × 1/2' Pl.	0.518	58 000	79 900	10.30	16.30	84 900	94 700
6b	"	"	"	"	"	"	81 000	95 000
7.......	4'' × 3/8" Pl.	0.390	......	125 800	in 2'' = 7.50 " 3'' = 6.67 " 4'' = 6.25 " 5'' = 6.00 " 6'' = 7.50	4.41	87 000	98 000

).

STEEL.

9	10	11	12	13	14	15	16
…ING TEST.	RESULTS OBTAINED BY CALCULATION.				ANALYSES.		
Pressure applied in pounds to punch with ⅞-in. punch.	$\frac{P}{c \times t}$ with ¾-in. diameter punch.	$\frac{P}{c \times t}$ with ⅞-in. diameter punch.	Percent. of $\frac{P}{c \times t}$ with ¾-in. diameter punch to ultimate strength.	Percent. of $\frac{P}{c \times t}$ with ⅞-in. diameter punch to ultimate strength.	Carbon. Percent.	Manganese. Percent.	Phosphorus. Percent.
67 900	66 570	64 370	93.50	90.42	0.16	0.90	0.087
68 300	67 240	64 750	94 44	90.95	"	"	"
71 800	69 230	66 610	93.45	89.90	0.21	0.65	0.091
71 500	69 010	66 330	93.14	89.53	"	"	"
87 100	[illegible]3 460	68 530	89.36	83.39	0.26	0.53	0.115
87 500	74 090	68 840	90.13	83.75	"	"	"
78 300	54 780	52 040	77.37	73.50	0.18	0.57	0.091
80 100	56 400	53 240	79.66	75.20	"	"	"
82 900	59 340	56 190	77.67	73.53	0.15	0.51	0.125
84 500	60 670	57 280	79.41	74.98	"	"	"
94 700	65 210	62 570	81.61	78.31	0.17	0.41	0.145
95 000	62 220	62 770	77.87	78.57	"	"	"
98 000	88 760	86 020	70 56	68.37	0.71	0.14	0.079

TA

WEAK AND

1	2	3	4	5	6	7	8	9
Specimen Number.	Remarks on Quality.	Description cut from—	Thickness of Specimen.	Tensile Test.				P
				Elastic limit per square inch.	Ultimate strength per square inch.	Elongation in 8 ins. Percent.	Reduction of area. Percent.	Pressu plie poun punch $\frac{3}{4}$-in. p
1a....	Poorly made—rotten.	2 x 3 x $\frac{5}{16}$" L.	0.313"	30 100	47 800	19.80	38.50	30
1b....	"	"	"	"	"	"	"	29
2a....	Badly burned.	3 x 3 x $\frac{3}{8}$" L.	0.390"	35 400	61 000	8.50	12.20	37
2b....	"	"	"	"	"	"	"	36
3a....	Poorly made.	3 x 3 x $\frac{3}{8}$" L.	0 379"	32 500	48 900	17.50	33.10	39
3b....	"	"	"	"	"	"	"	40
4a....	Weak steel.	16 x $\frac{7}{16}$" Pl.	0.445"	30 900	48 300	16.30	31 20	45
4b....	"	"	"	"	"	"	"	44
5a....	"	20 x $\frac{1}{2}$" Pl.	0.523"	32 200	46 000	18.90	31.90	50
5b....	"	"	"	"	"	"	"	50
6a....	Not sufficiently worked.	10 x $\frac{3}{4}$" Pl.	0.770"	37 400	58 800	15.25	36.50	62
6b....	"	"	"	"	"	"	"	64
7a....	"	12 x $\frac{7}{8}$" Pl.	0 900"	39 800	64 300	17.10	28 20	......
7b....	"	"	"	"	"	"	"	......
8.....	Burned.	7 x $\frac{13}{16}$" Pl.	0.810"	......	......	......	......	90

TABLE E1.

Weak and Rotten Steel.

	9	10	11	12	13	14	15
	Punching Test.		Results Obtained by Calculation.				
...on of . ...nt.	Pressure applied in pounds to punch with $\frac{3}{4}$-in. punch.	Pressure applied in pounds to punch with $\frac{7}{8}$-in. punch.	$\frac{P}{c \times t}$ with $\frac{3}{4}$-in. diameter punch.	$\frac{P}{c \times t}$ with $\frac{7}{8}$-in. diameter punch.	Percent. of $\frac{P}{c \times t}$ with $\frac{3}{4}$-in. diameter punch to ultimate strength.	Percent. of $\frac{P}{c \times t}$ with $\frac{7}{8}$-in. diameter punch to ultimate strength.	Carbon. Per cent.
	30 100	34 400	38 270	37 615	80.06	78 49	0.12
	29 700	33 500	37 760	36 640	79.00	76.65	"
	37 400	42 000	38 160	36 860	62 56	60.45	0.10
	36 700	42 500	37 440	37 300	61.34	61.14	"
	39 900	44 700	41 890	41 650	85.68	85.18	0.14
	40 300	45 500	42 310	42 400	86.52	86.70	"
	45 500	50 200	40 680	38 610	84.22	79 94	0.087
	44 900	50 000	40 140	38 450	83.11	79.60	"
	50 800	56 400	38 650	36 920	84 02	80.26	0.067
	50 200	56 100	38 190	36 720	83.02	79.83	"
	62 000	72 000	32 040	32 010	54.49	54.43	0.16
	64 000	71 000	33 080	31 570	56 26	53.69	"
	....	74 000	....	28 150	....	43.78	0.19
	....	75 000	....	28 530	....	44.37	"
....	90 000	....	44 210				

15	16	17	18	19
	Analyses.			
arbon. Per ceut.	Man-ganese. Per cent.	Phos-phorus. Per ceut.	Sulphur. Percent.	Silicon. Per cent.
0.12 "	0.31 "	0.095 "	0.078 "	0.094 "
0.10 "	0.14 "	0.072 "	0.035 "	0.001 "
0.14 "	0.377 "	0.101 "	0.071 "	0.087 "
0.087 "	0.229 "	0.041 "	0.065 "	0.023 "
0.067 "	0.12 "	0.065 "	0.032 "	0.037 "
0.16 "	0.29 "	0.055 "	0.042 "	0.008 "
0.19 "	0.34 "	0.063 "	0.033 "	0.010 "

TAI

TESTS OF I

1	2	3	4	5	6	7	8	9
		PRESSURE REQUIRED TO PUNCH NORMAL SPECIMENS OF STEEL.						
Specimen Number.	Description cut from—	Actual pressure. $\frac{3}{4}$-in. punch P.	Actual pressure. $\frac{7}{8}$-in. punch P.	Pressure per square inch. $\frac{3}{4}$-in punch $\frac{P}{c \times t}$.	Pressure per square inch. $\frac{7}{8}$-in. punch $\frac{P}{c \times t}$.	Percent. $\frac{P}{c \times t}$ to ultimate strength. $\frac{3}{4}$-in. punch.	Percent. $\frac{P}{c \times t}$ to ultimate strength. $\frac{7}{8}$-in. punch.	Thicknes burned spec
1 a	6¾" x $\frac{3}{16}$" Pl.	21 600	25 200	46 450	46 610	70.68	70.92	0.105
b	"	"	"	"	"	"	"	"
2 a	3" x 3" x ¼" L.	28 300	31 800	45 970	50 320	74.64	72.14	0.145
b	"	"	32 200	45 970	50 320	"	73.04	"
3 a	3" x 3" x $\frac{5}{16}$" L.	37 000	41 500	47 500	45 830	77.90	75.16	0.210
b	"	36 800	41 600	47 240	45 830	77.48	"	"
4 a	10½" x ⅜" Pl.	45 700	46 800	49 810	43 880	85.32	"	0.270
b	"	44 000	48 900	47 960	45 850	82.16	78.54	"
5 a	25" x $\frac{7}{16}$" Pl.	51 200	58 300	47 370	46 410	76.55	74.98	0.365
b	"	51 600	58 400	47 730	46 490	77.10	78.09	"
6 a	20" x ½" Pl.	60 300	66 900	47 980	45 700	77.27	73.88	0.430
b	"	59 400	68 100	47 270	45 240	76.26	72.99	"
7 a	6" x 6" x $\frac{9}{16}$" L.	70 000	79 000	48 020	46 620	76.98	74.74	0.480
b	"	69 000	78 300	47 340	46 210	75.89	74.08	"
8 a	18" x $\frac{9}{16}$" Pl.	61 000	71 400	43 340	43 640	68.48	68.95	0.475
b	"	62 000	71 500	44 050	43 710	69.60	69.06	"
9 a	5" x 5" x ⅜" L.	74 000	83 300	49 070	47 520	78.66	76.18	0.525
b	"	74 300	83 200	49 270	47 460	78.98	76.10	"
10 a	6" x 6" x $\frac{11}{16}$" L.	86 000	93 100	51 070	47 570	83.58	77.89	0.600
b	"	85 500	93 700	50 830	47 870	83.20	78.34	"
11 a	6" x 6" $\frac{9}{16}$" L.	67 100	76 400	48 100	47 110	78.97	77.34	0.460
b	"	65 700	76 100	47 090	46 930	77.32	77.06	"
12 a	4" x 4" x ¾" L.	82 000	97 300	45 010	45 930	74.82	76.34	0.685
b	"	83 800	96 700	46 050	45 650	71.46	75.88	"
c	"	....	....	....	....	....	....	"
13 a	10" x ¾" Pl.	83 000	92 000	43 740	41 670	74.44	69.00	0.675
b	"	85 000	99 000	44 000	44 840	72.24	74.25	"
c	"	....	....	....	....	....	....	"
14 a	10" x $\frac{13}{16}$" Pl.	90 300	97 500	43 980	40 850	....	....	0.735
b	"	88 100	100 400	42 920	42 060	....	....	"
15 a	24" x ⅞" Pl.	101 000	114 000	45 640	44 340	78.86	76.62	0.810
b	"	....	107 000	....	41 630	....	71.94	"
c	"	....	....	....	....	....	....	"
16 a	6" x 6" x $\frac{13}{16}$" L.	117 000	120 000	49 630	43 800	79.92	70.54	0.720
b	"	110 000	120 000	46 600	"	75.14	"	"
17 a	6" x 6" x $\frac{15}{16}$" L.	....	119 000	....	44 760	....	....	0.840
b	"	....	....	....	....	....	....	"

TABLE E2.

TESTS OF BURNED STEEL.

9	10	11	12	13	14
	PRESSURE TO PUNCH SAME SPECIMENS OF STEEL AFTER BEING BURNED.				VARIANCE IN PRESSUR[E] OF THE SAME S[…]
Thickness of burned specimen.	Actual pressure in pounds. $\frac{3}{4}$-in. punch. P.	Actual pressure in pounds. $\frac{7}{8}$-in. punch. P.	Pressure per square inch. $\frac{3}{4}$-in. punch. $\frac{P}{c \times t}$.	Pressure per square inch. $\frac{7}{8}$-in. punch. $\frac{P}{c \times t}$.	Pounds variance. $\frac{3}{4}$-in. punch.
0.105	12 300	11 000	46 610	35 860	+ 160
"	11 500	....	43 580	....	− 2 870
0.145	16 900	17 800	46 070	42 020	+ 2 900
"	16 800	16 000	45 790	37 770	− 180
0.210	24 000	27 200	45 470	44 320	− 2 030
"	23 900	27 900	45 280	45 470	− 1 960
0.270	32 800	37 000	48 340	46 900	− 1 470
"	33 700	36 500	49 660	46 270	+ 1 700
0.365	42 100	46 100	45 880	43 280	− 1 440
"	41 100	44 700	44 800	41 970	− 2 930
0.430	51 500	58 000	47 640	46 180	− 340
"	50 000	55 700	46 250	44 340	− 1 020
0.480	58 800	68 400	48 750	48 780	+ 730
"	55 000	64 300	45 600	45 860	− 1 740
0.475	52 000	60 400	43 550	43 520	+ 210
"	53 200	57 400	44 550	41 350	+ 500
0.525	63 000	70 700	47 760	46 090	− 1 310
"	62 200	70 100	47 160	45 700	− 2 110
0.600	74 100	84 100	49 140	47 970	− 1 930
"	71 100	83 100	47 150	47 400	− 3 680
0.460	54 500	67 700	47 140	50 370	− 960
"	56 700	63 500	49 050	47 250	+ 1 960
0.685	70 200	83 800	40 770	41 880	− 4 240
"	70 000	80 100	40 650	40 030	− 5 400
"	68 100	....	39 550	....	....
0.675	79 600	89 200	46 930	45 240	+ 2 190
"	70 100	88 400	41 330	44 820	− 3 470
"	73 900	....	43 570	....	....
0.735	80 900	92 200	43 800	42 940	− 180
"	78 000	88 200	42 230	41 080	− 690
0.810	91 300	104 000	44 840	43 960	− 800
"	....	99 100	....	41 880	....
"	....	106 100	....	44 800	....
0.720	88 100	99 300	48 670	47 200	− 960
"	....	96 500	....	45 860	....
0.840	95 100	....	45 050		
"	93 000	....	44 650		

	15	16	17
…ressure With Burned Steel From That …ame Steel in the Normal State.			
…ce.	Percent. with $\frac{3}{4}$-in. punch of *U*.	Pounds variance with $\frac{7}{8}$-in. punch.	Percent. variance. $\frac{7}{8}$-in. punch of *U*.
	70.92	−10 750	54.56
	66.30		
	74.80	− 8 300	68.23
	74.34	−12 550	61.33
	74.58	− 1 510	72.70
	74.28	− 360	74.58
	82.82	+ 3 020	80.35
	85.08	+ 420	79.27
	74.09	− 3 130	69.91
	72.36	− 4 520	67.79
	76.86	+ 440	74.50
	74.61	− 900	71.53
	78.15	+ 2 160	78.20
	73.10	− 350	73.51
	68.81	− 120	68.76
	70.39	− 2 360	65.33
	76.56	− 1 430	73.81
	75.60	− 1 760	73.26
	80.43	+ 400	78.52
	77.16	− 470	77.59
	77.39	+ 3 260	82.70
	80.52	+ 320	77.57
	67.77	− 4 050	69.62
	67.57	− 5 620	66.54
……	65.74		
	77.72	+ 3 570	74.91
	68.44	− 10	74.23
……	72.15		
	…………	+ 2 090	
	…………	− 980	
	77.48		79.42
……	…………	− 2 460	72.37
……	…………	+ 3 170	77.41
	78.37	+ 3 400	76.00
……	…………	+ 2 060	73.84

TABLE F.

STEEL OVER $\frac{5}{8}$-IN. THI

1	2	3	4	5	6	7	8	9
			TENSILE TEST.				PUNCHING TEST.	
Specimen Number.	Description cut from —	Thickness of specimen.	Elastic limit per square inch.	Ultimate strength per square inch.	Elongation in 8 ins. Percent.	Reduction of area. Percent.	Pressure applied in pounds to punch with $\frac{3}{4}$-in. punch.	Pressure applie in pounds to punch with $\frac{7}{8}$-in punch.
1........	4 x 4 x $\frac{11}{16}$" L.	0.690"	40 000	61 300	24.25	48.50	80 100	89 100
2........	" "	0.683"	42 500	64 800	23.75	45.80	84 200	94 000
3........	12 x $\frac{11}{16}$" Pl.	0.688"	41 300	62 500	25.30	51.70	81 300	92 100
4........	10 x $\frac{3}{4}$" Pl.	0.755"	37 100	58 200	25.70	53.30	82 100	93 300
5........	" "	0.764"	36 300	56 100	27.10	57.25	80 400	88 700
6........	10 x $\frac{13}{16}$" Pl.	0.817"	39 300	59 800	29.25	59.30	90 300	97 500
7........	" "	0.820"	40 700	64 500	24.80	50.70	92 100	101 400
8........	24 x $\frac{7}{8}$" Pl.	0.870"	39 500	60 400	25.80	57.75	101 000	114 000
9........	20 x $\frac{7}{8}$" Pl.	0.878"	42 000	61 600	24.90	49.50	98 300	107 200
10........	6 x $\frac{7}{8}$" bar.	0.882"	44 000	65 900	23.25	45.80	99 900	106 500
11........	6 x 6 x $\frac{15}{16}$" L.	0.910"	40 100	62 200	23.00	44.50	97 500	105 700
12........	" "	0.920"	35 300	54 500	25.10	47.70	97 100	104 200
13........	21 x 1" Pl.	1.010"	39 200	59 300	24.60	48.80	....	121 000
14........	8 x 1" bar.	1.008"	37 500	62 400	25.10	49.90	....	120 400

TABLE F.

…ER $\frac{5}{8}$-IN. THICKNESS.

9	10	11	12	13	14	15
…NG TEST.	RESULTS OBTAINED BY CALCULATION.				ANALYSE…	
Pressure applied in pounds to punch with $\frac{7}{8}$-in. punch.	$\frac{P}{c \times t}$ with $\frac{3}{4}$-in. diameter punch.	$\frac{P}{c \times t}$ with $\frac{7}{8}$-in. diameter punch.	Percent. of $\frac{P}{c \times t}$ with $\frac{3}{4}$-in. diameter punch to ultimate strength.	Per cent. of $\frac{P}{c \times t}$ with $\frac{7}{8}$-in. diameter punch to ultimate strength.	Carbon. Percent.	Mangane… Percen…
89 100	46 200	44 200	75.38	72.12	0.15	0.35
94 000	49 060	48 960	75.70	75.56	0.17	0.42
92 100	47 030	45 820	75.25	73.30	0.24	0.41
93 300	43 260	41 850	74.32	71.90	0.13	0.58
88 700	41 860	39 710	74.62	70.78	0.20	0.39
97·500	43 960	40 850	73.51	68.32	0.13	0.53
101 400	44 690	41 900	69.29	64.96	0.13	0.51
114 000	46 180	44 820	76.46	74.19	0.25	0.51
107 200	44 540	41 800	72.30	67.86	0.14	0.49
106 500	45 060	41 830	68.45	62.73	0.15	0.44
105 700	42 630	39 750	68.56	63.91	0.12	0.57
104 200	41 960	38 770	77.00	71.14	0.12	0.34
121 000	....	41 000	....	69.14	0.11	0.58
120 400	....	40 880	....	65.52	0.22	0.47

15	16
NALYSES.	
anganese. Percent.	Phos-phorus. Percent.
0.35	0.075
0.42	0.072
0.41	0.011
0.58	0.060
0.39	0.007
0.53	0.077
0.51	0.073
0.51	0.009
0.49	0.035
0.44	0.085
0.57	0.094
0.34	0.043
0.58	0.092
0.47	0.018

TABLE G.

ACTION OF SPEED OF PUNCHING IN MO

1	2	3	4	5	6	7	8	9	10
Specimen Number.	Remarks on quality.	Description cut from—	Thickness of specimen.	PUNCHING TESTS—¾-IN. DIAMETER PUNCH.					
				Pressure applied in pounds to punch in 10 seconds.	Pressure applied in pounds to punch in 30 seconds.	Pressure applied in pounds to punch in 60 seconds.	Pressure applied in pounds to punch in 2 minutes.	Pressure applied in pounds to punch in 3 minutes.	Pressure a plied pounds punch 5 mi utes.
1......	Good steel..	5 x 3½ x ⅜" L.	0.423"	47 700	47 900	48 000	48 100	48 000	48 100
2......	" ..	10 x ⅜" Pl.	0.365"	41 000	41 100	41 200	41 200	41 200	41 100
3......	Hard steel..	"	0.367"	51 800	51 800	52 000	52 100	52 000	52 100
4......	Good steel..	"	0.362"	46 300	47 100	47 200	47 200	47 100	47 700
5......	" ..	3 x 3 x ⅜" L.	0.405"	46 800	47 600	46 900	47 000	47 400	47 500
6......	" ..	5 x 3 x ⅜" L.	0.370"	45 300	45 400	45 500	45 700	45 700	45 700
7......	" ..	4 x 4 x ⅜" L.	0.366"	43 000	43 400	43 500	43 400	43 500	43 500
8......	Hard steel..	15 x ¼" Pl.	0.256"	36 300	36 300	36 400	36 500	36 400	36 600
9......	Good steel..	16 x ½" Pl.	0.505"	56 000	56 100	56 400	56 500	56 200	56 300
10......	" ..	5 x 5 x ⅝" L.	0.610"	74 000	74 300	74 800	75 000	75 200	75 500
11......	" ..	6 x 6 x 11/16" L.	0.680"	85 500	85 600	85 900	86 000	86 200	86 400
12......	" ..	4 x 4 x ¾" L.	0.770"	82 000	82 800	83 500	83 700	83 800	83 800

LE G.

NG IN MODIFYING THE RESULTS.

10	11	12	13	14	15	16	17	18
NCH.		PUNCHING TESTS—⅝-IN. DIAMETER PUNCH.						
Pressure applied in pounds to punch in 5 minutes.	Pressure applied in pounds to punch in 10 minutes.	Pressure applied in pounds to punch in 10 seconds.	Pressure applied in pounds to punch in 30 seconds.	Pressure applied in pounds to punch in 60 seconds.	Pressure applied in pounds to punch in 2 minutes.	Pressure applied in pounds to punch in 3 minutes.	Pressure applied in pounds to punch in 5 minutes.	Pressur plied poun punc 10 m utes.
48 100	48 100	52 400	52 600	52 800	52 800	52 900	52 900	52 8
41 100	41 400	46 700	46 800	46 700	46 800	46 900	47 000	46 8
52 100	52 100	58 400	58 100	58 200	58 300	58 400	58 500	58 5
47 700	47 500	53 300	53 900	53 800	53 500	53 900	54 000	53 6
47 500	47 200	54 200	54 100	54 300	54 400	54 400	54 400	54 5
45 700	45 700	52 100	52 300	52 300	52 500	52 600	52 500	52 5
43 500	43 500	50 200	50 100	50 200	50 400	50 500	50 300	50 4
36 600	36 500	39 700	39 900	39 900	40 100	40 200	40 100	40 1
56 300	56 400	64 200	64 300	64 300	64 400	64 600	64 600	64 5
75 500	75 600	83 200	83 300	83 900	83 800	84 000	84 100	84 0
86 400	86 500	90 300	90 700	91 200	91 900	91 700	91 800	91 7
83 800	83 700	96 700	96 800	97 000	97 100	97 300	97 200	97 3

18

Pressure applied in pounds to punch in 10 minutes.
52 800
46 800
58 500
53 600
54 500
52 500
50 400
40 100
64 500
84 000
91 700
97 300

1	2	3	4	5a	5b	6a	6b	7a	7b
Specimen Number.	Remarks on Quality.	Description cut from—	Thickness of Specimen.	Pressure applied in pounds to punch hole whose center is 3 in. from edge of plate.		Pressure applied in pounds to punch hole whose center is 2 in. from edge of plate.		Pressure applied pounds to punch h whose center is 1½ from edge of plate.	
				$\frac{3}{4}$" Punch.	$\frac{7}{8}$" Punch.	$\frac{3}{4}$" Punch.	$\frac{7}{8}$" Punch.	$\frac{3}{4}$" Punch.	$\frac{7}{8}$" Punch.
1....	Hard steel.	4 x $\frac{3}{8}$" bar.	0.390"	87 000	98 000	86 500	99 000	87 500	97 800
2....	Good steel.	7 x $\frac{13}{16}$" bar.	0.810"	90 000	....	....	......	89 800	....
3....	"	6 x 3½ x $\frac{7}{16}$" L.	0.460"	....	....	....	61 500	....	61 500
4....	"	24 x $\frac{7}{16}$" Pl.	0.435"	....	56 200	....	56 300	....	56 300
5....	"	6½ x $\frac{9}{16}$" Pl.	0.562"	67 500	75 600	67 700	76 200	67 100	75 800
6....	"	10 x $\frac{3}{8}$" Pl.	0.365"	44 200	....	44 000	......	43 700	....
7....	"	10½ x $\frac{3}{8}$" Pl.	0.365"	45 700	50 500	45 500	51 000	45 200	50 700
8....	"	3 x 3 x $\frac{1}{4}$" L.	0.210"	24 000	27 200	24 100	27 400	24 300	27 500
9....	Burned steel.	3 x 3 x $\frac{3}{16}$" L.	0.145"	16 900	17 800	17 000	18 500	17 200	18 100
10....	Good steel.	20 x $\frac{1}{2}$" Pl.	0.510"	60 300	66 900	60 300	66 800	60 100	66 800

TABLE H.

Variations Due to Location of Punched Holes and Their Environment.

	7b	8a	8b	9a	9b	10a	10b	11a	11b	12a	1
e applied in ds to punch hole e center is 1½ in. edge of plate.		Pressure applied in pounds to punch hole whose center is 1½ in from rolled edge and 1¼ in. from center of adjoining similarly punched hole.		Pressure applied in pounds to punch hole whose center is 1 in. from rolled edge of plate.		Pressure applied in pounds to punch hole whose center is 1 in. from sheared edge of plate.		Pressure applied in pounds to punch hole whose center is ¾ in. from rolled edge of plate.		Pressure applie pounds to punc whose center is from rolled edge	
ch.	$\frac{7}{8}$" Punch.	$\frac{3}{4}$" Punch.	$\frac{7}{8}$" Punch.	$\frac{3}{4}$" Punch.	$\frac{7}{8}$" Punch.	$\frac{3}{4}$" Punch.	$\frac{7}{8}$" Punch.	$\frac{3}{4}$" Punch.	$\frac{7}{8}$" Punch.	$\frac{3}{4}$" Punch.	$\frac{7}{8}$" P
00	97 800	87 500	96 200	86 000	96 000	84 000	92 000	83 000	92 000	80 000	87
00	....	89 500	....	90 000	....	86 800	....	88 000	....	85 000	......
.....	61 500	....	60 300	....	61 200	....	60 300	....	58 000	....	57
.....	56 300	....	56 000	....	56 000	....	55 000	....	55 600	....	54
00	75 800	66 900	75 200	66 100	74 200	65 000	74 000	65 100	74 500	64 700	73
00	....	43 200	....	43 200	....	42 700	....	43 100	....	42 100	......
00	50 700	45 100	50 900	45 100	50 100	44 700	50 000	44 200	49 800	43 700	49
00	27 500	24 200	27 100	24 500	27 700	23 200	26 500	23 900	27 900	23 100	26
00	18 100	17 100	18 000	16 700	18 000	16 000	17 500	16 200	17 900	15 800	17
00	66 800	60 000	67 100	59 800	66 600	59 600	66 200	57 900	66 000	57 700	65

12b	13a	13b	14a	14b	15a	15b	16a	16b	17a	17b
applied in … punch hole … ter is ⅜ in. … d edge.	Pressure applied in pounds to punch hole whose center is ⅝ in. from rolled edge.		Pressure applied in pounds to punch hole whose center is ⅝ in. from sheared edge.		Pressure applied in pounds to punch hole whose center is ½ in. from rolled edge.		Pressure applied in pounds to punch hole whose center is ½ in. from sheared edge.		Pressure applied … pounds to punch ho… whose center is ½ i… from planed edge.	
⅞" Punch	¾" Punch.	⅞" Punch.	¾" Punch.	⅞" Punch.	¾" Punch.	⅞" Punch	¾" Punch.	⅞" Punch.	¾" Punch.	⅞" Punch
87 000	79 000	87 900	74 000	76 000	71 200	73 000	69 100	68 000	70 000	71 500
....	83 000	....	79 000	....	79 200	....	73 000	....	82 200	
57 300	....	57 100	....	55 200	....	55 100	....	52 000	....	55 400
54 500	....	54 100	....	53 700	....	53 500	....	52 000	....	52 800
73 800	65 100	73 900	64 300	72 500	63 800	72 900	62 000	71 400	63 900	73 100
....	41 500	....	40 600	....	40 700	....	40 100	....	40 900	
49 500	44 000	49 100	43 600	48 500	44 100	48 900	43 700	48 100	44 400	49 000
26 300	23 700	26 500	23 000	25 800	23 100	25 900	22 700	25 000	23 000	26 100
17 000	15 900	17 100	15 300	16 100	15 200	16 200	14 800	16 000	15 000	16 400
65 400	57 800	65 500	57 100	65 000	58 200	64 400	56 100	64 000	56 500	64 700

Emery testing machine, and the remarkable uniformity of the results is shown in Table G. In a general way, the pressure applied rapidly, as in 10 seconds, gives slightly lower results than when the same conditions are varied only by the time being considerably longer in applying the pressure upon the punch. The entire difference, however, is very slight, comparatively, and will not be a cause of error in this method of testing steel by any ordinary variances due to speed.

Ten seconds is about as short a time as it has been found practicable to make a punching and record its results with the apparatus at the writer's command.

APPENDIX H.

Variations in Power Required in Punching Due to Location of Punched Holes and their Environment.

Both $\frac{3}{4}$ and $\frac{7}{8}$-in. holes were punched in varying locations in steel specimens. The results are given in Table H, which is self-explanatory.

Holes punched near the sheared edge require from 10 to 20% less work than those punched nearer the center of the plate or angle, the loss being greater with hard steel than with soft. Slight differences in location of the center of the punch do not seem to make great differences, not over at most 1 000 lbs. or so, in the results.

As a rule, plates tested by this method show slightly higher shearing strength than angles or other shapes of the same steel. The writer's experience is that both the tensile and the shearing strength of universal mill-plates increases by from 5 to in some cases 10%, as the test specimens are selected towards the center of the plates, from the results obtained in test specimens selected near the edge of the plate. This fact is made use of at the mills in the selection of tensile test specimens to fill varying requirements.

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THE USE OF MILD STEEL FOR ENGINEERING STRUCTURES.

By GEORGE C. MEHRTENS, Regierungs- und Baurath, Member of Royal Board of Railway Directors at Bromberg, Prussia.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

The importance of mild steel as material for use in engineering structures, and its probable adoption in the construction of bridges, was noted by the author in an article published in 1882.* The distrust in such use will surely disappear more rapidly than did the prejudice against puddled and rolled iron as opposed to that fined in the hearth and forged under the hammer.

More than 10 years have passed since, and in consequence of the general adoption of the inventions of Martin and Thomas, there has been an enormous increase in the production and use of low steel; and

* Notice respecting fabrication of iron and iron bridges, "Deutsche Bauzeitung," 1882.

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

in the choice of material for important structures, wrought iron and mild steel are now considered equivalent, although a few prefer the former, and that mostly from ignorance.

In face of the numerous engineering structures now existing which have been built of mild steel, there cannot be any well-founded objection to its use. There are, however, in this much-debated field many questions yet awaiting solution, and he who will conscientiously decide them has much labor before him. To aid those who are still undecided, those who favor the use of mild steel should agree and do their part in spreading a knowledge of its qualities and advantages. The author has been for many years such an advocate and takes pleasure in embracing this opportunity to make his opinions known.

Mild steel up to the year 1860 had not been used for engineering structures, neither had the Bessemer process come into general use before that time—the only materials available were weld steel and cast steel.*

Cast steel is often called ingot steel (*fluss-stahl*) but this is not correct. The term ingot steel to-day includes generally only those kinds produced directly by a single melt from the raw materials. Cast steel is made by several meltings from the ingot metal, and, therefore, does not belong to them. The beginning of the use of ingot steel for structures was contemporaneous with the development of the Bessemer process, and one of its first applications was to the building of merchant ships in England. The first of these was the *Jason*, an English ship of 452 tons burden and destined to ply in the Black Sea. Five channel steamers of the London, Chatham and Dover Railway were built in 1860 and 1861. The next step was the use of Bessemer steel in building boilers in men-of-war and railway locomotives in France and America in 1861 to 1864; also, in England the manufacture from the same material in 1865 of driving shafts for marine engines. It was used in bridges of the Dutch State railways in 1863–64. Owing to the irregular quality and occasional brittleness of Bessemer steel, adoption

* It is worthy of note that the first adoption of weld steel in bridge-building (1818) was by Mitis for the Charles chain bridge over the Danube canal at Vienna. The steel used for railways, war material, and especially for rails, tires, axles, guns, etc., was crucible cast steel. At the Exposition in London, in the year 1851, the far-famed Krupp works at Essen made the first exhibition of heavy cast-steel ingots and barrels of heavy guns; at that Exposition also was to be seen German puddled steel of the work of Lohage, at Haspe, in Westphalia. At the Paris Exposition, in 1855, was exhibited the first cast-steel boiler from the French works of Petin, Gaudet & Co.

of it for ship-building made slow progress, as these made its manipulation very difficult.

The extensive steel works of Terre Noire, in France, prominent in this department of metallurgy, made every effort to produce a mild ingot steel. In the years 1868 and 1869 the Transatlantic Company supplied a mild ingot steel, 64 000 to 71 000 lbs. tenacity per square inch (45 to 50 kg. per square millimeter), and 18 to 26% elongation on a testing piece 4 ins. long. The authorities of the French railways decided that the material was not suitable for locomotive boilers and preferred an ingot steel of at least 78 000 lbs. tenacity per square inch (55 kg. per square millimeter). Plates of 68 000 to 75 000 lbs. per square inch (48 to 53 kg. per square millimeter), with 20 to 24% elongation, were often refused as being unsuitable.

In 1870 the Terre Noire works offered to the French navy to supply plates and angles of soft Bessemer steel to take the place of wrought-iron plates and angles; they had then succeeded, by the plentiful use of ferro-manganese, in producing satisfactory plates. The Navy Department at first refused to accept such plates, but finally allowed their use in ship-building. In 1874 the first French man-of-war named the *Redoutable* was built of mild steel. She was a first-class armor-plated frigate 302 ft. long and 64 ft. beam. These works, and those of Creuzot, together, furnished the plates and bars, which were manufactured partly by the Bessemer process and partly by the Martin open-hearth process. The requirements were a tenacity between 64 000 to 68 000 lbs. (45 to 48 kg. per square millimeter), and of 18 to 22% elongation. The successful use of mild steel for ships by the French decided their engineers upon building marine boilers of the same material, with the exception of the fire-plates, and had a great influence on the adoption of the material by English engineers for ships and boilers.*

The Pennsylvania Railroad Company first introduced Bessemer steel in America in locomotive boilers in the year 1863, but the steel was too hard and brittle for such use, and this road was deterred from making further experiments in that direction.

* In the beginning of 1878 Mr. Parker, Chief Engineer of Lloyd's, stated that there was then but one English steamer in possession of a steel boiler; a year later there were 120, and in 1881 about 1 100 steel boilers weighing 1 700 tons total. In 1878 there were but five large English steamers built of steel, while in 1883 there were 116 building.

As the material came more largely into use, complaints against the irregularity of the material became more frequent, the principal difficulty being its hardness as well as its irregularity; and not only that, but those using the metal had not yet learned its proper treatment, and the plates were too thin. The first plates made for steel boilers had a tenacity of 85 000 to 92 000 lbs. (60 to 65 kg.), and an elongation of but 7 to 10%; and it was supposed that with this much greater strength it would be possible to materially diminish the thickness of the plates below those made of wrought iron. Soon after the World's Exposition in 1855, where the first cast-steel boiler appeared, the French authorities allowed the makers to diminish the thickness of the plates one-third from that which had been required in wrought iron since the year 1843. In 1861 the reduction in thickness for steel having a tenacity of 85 000 lbs. (60 kg.) and 6.6% elongation was one-half from that of wrought iron; but the results were not favorable, and the steel works were soon forced to offer a material of less tenacity and more ductility. The requirements were therefore reduced to a tenacity of 78 000 lbs. (55 kg.) or less, and the elongation was increased to 15% or more. Even with this, between the years 1870 and 1880, many explosions occurred and many careful examinations were made to determine their cause. It was found on examining the rivet holes that there were incipient changes in the metal, many cracks around them, and points near them were corroded with rust, all caused by the shock of tools in manufacturing. It was evident that the material was unsuitable, and that the treatment must be changed. The use of Bessemer steel in bridge-building was very early tried, as was previously mentioned. First on the Dutch State railways in 1863–64, then in England and Austria. Following the use of steel in the bridges of the Dutch railways, in 1874 a bridge was built of Bessemer steel, crossing over the railway at the station of Pesth, by H. Schmidt, engineer. Several superstructures of bridges on the branch line of Ebersdorf-Würbenthal, have been built since 1881.

The first use of cast steel for bridges was in America, for the St. Louis Arch Bridge and for the wire of the East River Bridge. These gave an impetus to the use of ingot metal, and before 1880 the Glasgow and Plattsmouth bridges over the Missouri River were also built of ingot metal. For the superstructure for the bridge in Glasgow, steel eye-bars were applied for the first time.*

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* *Transactions* Am. Soc. C. E., October, 1892.

While in the 10 years succeeding 1860, Bessemer metal was most widely used, on account of bad failures in its use in ships, the open-hearth metal came slowly to be preferred by engineers. From 1870 to 1880, experiments were made in Europe in building bridges and other structures of Martin open-hearth metal; these were induced doubtless by the unsatisfactory results of the introduction of Bessemer metal in the large span bridges of the Dutch State railways. The invention of Thomas in 1878, and its use with the Martin furnace in 1882, removed the distrust and prejudice then existing.

Since 1880 the introduction of mild steel in all kinds of engineering structures has steadily increased.

Table No. 1 gives a connected statement of the most remarkable mild-steel bridges built in Europe in 1880 to 1890. This excludes those in acid Bessemer metal.

The writer was unable to make this complete for American bridges because distinction is not there usually made in the description as to whether the steel employed was Bessemer or Martin steel, and also because some of the information sought for by American bridge works was not obtained.

In the table the countries of Central Europe including France are mostly represented; this is by reason of the dominance in England and America of the acid Bessemer metal up to the year 1880. In the first design of the Forth Bridge, 1881–82, this metal was provided, and in America, as stated, there were in 1880 but two bridges of this material. English publications respecting steel bridges, as also those of America, do not name the kind of steel used, although English steel works furnished several bridge superstructures in mild steel for foreign countries, among them the well-known Sukkur Bridge for the India North West Railway; the Chenal Bridge, for the India State Railway, 17 spans of 206 ft. each. In England also a remarkable railway swing bridge over the Dee, designed by Mr. Fox, 2 truss spans each 120 ft. long, and a swing bridge having unequal arms of 140 and 86 ft. each, and 727 tons weight. The links of the Hammersmith Suspension Bridge over the Thames were of mild steel.

The use of basic mild steel for bridges increased most rapidly in those countries in Central Europe which first adopted it, especially Germany, Austria and France, while the use of acid Martin metal predominated in England and America. So far as is known the first mild-

steel bridges were erected in the years 1880–82, at Königsberg, in Prussia, by City Engineer Frühling. These were draw-bridges, and the object in using steel was to lighten them as much as possible. In 1885, Harkort, at Duisburg, introduced Thomas metal for a large bridge to be erected in Sumatra. Basic Martin steel bridges were erected in Austria and France in 1886–87, and in 1881* the great Bohemian works at Kladno in Austria-Hungary first produced plates and bars by the Thomas process, while the first Bohemian mild-steel bridge, which was a bridge with a single bowstring girder span 158 ft. long, over the Elbe at Nemcic, was still built of acid Bessemer metal. After the year 1887, the table names several Bohemian road-bridges built of Thomas and Martin mild steel, also railroad bridges.

A committee of the Austrian Society of Engineers and Architects made exhaustive experiments with satisfactory results on Martin open-hearth steel, after which it was adopted on the Austrian State railways.† It was probably these results which induced a promulgation of a ministerial order on January 29th, 1892, excluding Thomas mild steel entirely from use in bridges built on these roads. Later experiments,‡ however, with both kinds of metal, by the Government at Prague, seemed to give equally good results with each.

There are natural reasons why up to the present time the acid Martin metal has been preferred to Thomas metal for use in structures. The Martin process originated 13 years earlier than the invention of the dephosphorizing process in the Bessemer converter, and had therefore begun to be widely used, and it was difficult for the Thomas metal to make headway. If recently the Thomas metal has been more favorably looked upon, it will doubtless be due to the favorable results of comparative tests made by the Prussian State Railway Board in the year 1889, and since that date, in connection with the erection of the large Weichsel bridges near Dirschau, Marienburg and Fordon. These results have been published in several technical papers.§

The Prussian State Railway Department intended to use mild steel for the superstructures of the new bridges at Dirschau and Marienburg; but it was not thought desirable, not because of distrust of the material, but on account of the possible delays. There was at the time

* Tetmayer. A contribution for the mild-steel question, Schweizer Bauzeitung, 1892.

† "Allgemeine Bauzeitung," 1891, Part 2.

‡ Published by Professor Steiner at Prague. "Zeitschrift des Oesterreichischen Ingenieur und Architekten Vereines," 1892, Nos. 8 and 10.

§ "Stahl und Eisen," 1891, Nos. 8 and 9. "Centralblatt der Bauverwaltung," 1891, p. 395.

an abundant supply of mild steel of proper quality available, but the necessary testing and inspection of such large quantities of material, 7 000 tons for the Weichsel Bridge and 1 500 for the Nogat Bridge, could not be completed in the time stipulated. For these reasons the use of low steel was limited to some of the highly strained members in the two bridges, and it was decided to construct a smaller bridge over the Wallgraben at Marienburg (No. 17, Table No. 1) as a preliminary test, using low steel throughout. Martin steel alone was provided for in the bridge, because at the time of drawing the specifications Thomas steel was not thought sufficiently reliable, and yet it was impossible to resist the conclusion that Thomas metal could have been used for many purposes without scruple.

The results of the tests mentioned above were so favorable for the Thomas metal that this material was admitted on a large scale, together with Martin mild steel, in the construction of the Fordon Bridge over the Weichsel.

Up to the beginning of the present year tests have been made from about 1 200 blows containing nearly 10 000 tons of finished products. These have been most carefully made by tension, bending, and drop tests. Bending tests have been made after subjecting the specimens to a very low temperature. Results of the tests are shown in Plates I and II; they represent 700 blows for the Thomas and 500 for the Martin steel. Not a single blow of the Thomas steel failed, but 16 blows of the Martin steel were not satisfactory.*

The Royal Board of Directors in Bromberg, and the writer, have been in receipt of many inquiries from German and foreign departments respecting these tests, and it is evident that the successful use of basic steel in the prominent bridges over the Weichsel has given great impetus to its general adoption for bridge structures.

Table No. 2 gives a concise summary of the most remarkable mild-steel bridges erected during the years 1890–93 in Europe. Many small bridges have been omitted from this table. Acid metal has been excluded because it is now used but very little. †

* "Stahl und Eisen," 1892, No. 13, and 1893, No. 7. "Zeitschrift des Vereines Deutscher Ingenieure," 1892, Vol. 36, p. 778. "Centralblatt der Bauverwaltung," 1892, pp. 68, 83 and 285. "Le Genie Civil," 1892, p. 5–11. "The Engineering and Mining Journal," 1891, December, pp. 678–703.

* "Stahl und Eisen," April, 1893, p. 275.

† In Switzerland the Gothard Railway first adopted mild steel for several superstructures of bridges in the year 1891. In the beginning of 1892, the Northeast Railway followed.

This table shows that basic Martin steel has been preferred for bridge-building, and the same is true in ship-building. The first tests made in the years 1883–85 with Thomas metal by the English for use in ships were not successful, so that Lloyd's in December, 1885, determined not to admit it for such use. Recently, by the request of Mr. Percy G. Gilchrist, the English Admiralty have made additional tests upon this metal, and it was found to weld better, to be less dangerous at blue heat than the acid steel, and to accord with the requirements made in English ship-building. In Germany it has not been largely used for ship-building, because the ship-registering societies seem to consider Martin metal preferable. The writer's opinion, based on comparative tests and the examples of their use, given in the table, is that to-day there is no longer reason to prefer one kind of mild steel to the other, and that the selection should be governed by price alone. If this be admitted it would seem that the Thomas metal would have the preference, as by it large masses of metal can be produced, and the large amount of scrap which is used with the Martin metal must increase its price.

The production in the whole world in 1892 was as follows:

Of Thomas steel........................	2 591 374 tons.
Of basic Martin steel only..............	611 266 "

The distribution of manufacture is given in Table No. 3.

This table shows the important part Germany has taken in the production of this metal. Its production has been almost five times that of England and nearly eight times that of France. There is now no country where the milder metal is not received with confidence as being more desirable than the harder ingot metal for use in structures. Harder metal with a tenacity of 64 000 lbs. (45 kg.) is more easily produced by the acid Bessemer and the Martin process, while the basic open-hearth process is the most satisfactory for producing the lowest and more reliable metals, having a tenacity of 48 000 to 56 000 lbs. (38 to 45 kg.).

The specifications now prescribed by some of the States of Europe for the delivery of mild steel are given in Table No. 4. There are also given some of the earlier requirements, particularly those for vessels and boilers, which are still legal.

This table shows that everywhere in ship-building harder kinds of

metal than in bridge-building are still preferred. These requirements originated from the early English experience when only the acid Martin open-hearth process and the acid Bessemer process were in operation. Moreover, the acid Martin process did not allow the production of softer metals. The later development of the basic process furnishes a cheap and uniform quality of metal with a mean tenacity of 57 000 lbs. (40 kg.).

The introduction of this soft steel in ship-building would be of great advantage to the duration and safety of vessels, and that this is not the case seems to proceed from reluctance to the giving up of old customs and to the widespread error which ascribes to harder metal of high tenacity a greater resistance than to the softer. If this idea were correct it would be possible to lessen the thickness of steel proportionately and to increase the profit in ship-building by diminishing as much as possible the weight of material required. The resisting power of the metal does not, however, depend entirely upon its tenacity, but also upon its toughness, and the combined effort can be reached by the product of the tenacity and elongation, which product is called the resilience of the metal. It will be found that the softer kinds of metal always have a resilience which is very difficult for harder metal and quite impossible for a very hard one.

It is yet uncertain whether steel will in the future be produced of so high a tenacity as 64 000 to 85 000 lbs. (45 to 60 kg.) which shall be as ductile as that now produced having a tenacity of 57 000 to 64 000 lbs. This possibility is not excluded at all events, if the product be entirely free from the impurities of silicon, phosphorus and sulphur, and if the quantity of manganese used be kept low. The resultant product would be a pure mild steel, showing in the best manner the influence of the most important element, "carbon," upon its quality; but, so long as this result has not been reached, ingot metal of low tenacity offers for engineering structures more security than the harder kinds. Such steel stands better than the harder kinds under the operations of drilling, punching and other mechanical operations, and requires less care in manipulation.

On account of its uniformity of texture, ingot steel has been surnamed "homogeneous iron," and it is preferred to wrought iron, for the reason that it has high and uniform elongations in all directions, while the elongation of wrought iron transversely to the direction of

rolling is very small. The yield point of mild steel is one and one-half times to twice that of wrought iron. In a wrought iron bar considerable elongations begin with a load of 23 000 lbs. per square inch, but in a mild steel bar only when the load is at least 34 000 lbs. per square inch. Hence, if we fix the limit at one-half the yield point we may require a work in its use at least one and one-half times that of wrought iron, or, say, 17 000 lbs.

On account of the increase of elongation with the diminution of tenacity of the metal, many engineers have had the opinion that it was sufficient in testing steel to measure only the elongation, and they have insisted upon the highest attainable elongation as being a special requirement. This would exclude material which was too hard, and was, therefore, right in that respect; but there was danger of getting too soft a metal. It was therefore necessary to prescribe both an upper and a lower limit for the tenacity. Table No. 4 shows that most countries desire a steel for structures whose tenacity is between 50 000 and 64 000 lbs. France, however, somewhat unaccountably stipulates at least 60 000 lbs., and an elongation of at least 22 per cent. The requirements made by the Austrians seem somewhat high in consideration of the present state of steel manufacture.

The question of a correct specification for the transverse elongation of test pieces does not seem to be at present quite clear. The former standard by which rolled steel was required to have the same elongation in both directions does not seem to be upheld by experience. The subject has been exhaustively treated for the first time by the committee of the societies of German engineers and German steel-work managers, and is given in their standard specification for the use of mild steel. By request of the committee the great German steelmakers have made tests established upon universal bars and plates.* The averages of these results are given in Table No. 5.

This table shows that steel of 53 000 to 63 000 lbs. (37 to 44 kg.) tenacity and 20% elongation will not give equal stretch transversely and longitudinally without a rejection of about 27% of the universal bars tested, and 12% of the plates. If the requirements be a tenacity of 51 000 to 64 000 lbs. (36 to 45 kg.), and 17% elongation transversely, there will yet be a rejection of 10% in universal bars and 4% in plates.

* The tests were made in the Gutehoffnungshütte at Sterkrade, and the results have been published in "Stahl und Eisen," and in the "Zeitschrift des Vereines Deutscher Ingenieure."

In the writer's opinion the ascertaining of the transverse elongation of mild steel has more of scientific than of practical value, and the requirement of a certain degree of such elongation for various kinds of iron makes the reception of the material more difficult without giving an essentially better material. Aside from careful rolling we should aim to obtain a sufficient ductility longitudinally, and the lower transverse ductility caused by the rolling should be considered as unavoidable. It seems necessary for plates strained in this direction, especially joining plates, to take care that the ductility be as uniform as possible in every direction, and this requirement can be easily reached by suitable transverse rolling. Some authorities have proposed to specify a certain minimum transverse elongation and to neglect testing lengthwise; but this does not seem wise, and it seems sufficient to provide for a testing of the transverse ductility only in plates which will be strained in a transverse direction.

Table No. 4 shows that for rivets steel is demanded of less tenacity and more elongation than that for plates or bars, the tenacity required being 50 000 to 60 000 lbs. (35 to 42 kg.), and the elongation reaching 32 per cent. This requirement evidently arises from the opinion that rivet steel should not be so hard as to make riveting difficult, but there should be no scruple in stipulating the same tenacity and elongation for rivets and screw-plates as are generally prescribed for bars and plates. Still, there are yet some departments which prefer to use wrought-iron rivets in mild-steel structures. This proceeding appears unintelligible.

The fixing of the exact limit of elasticity being difficult, many engineers are content with the ascertainment of the yield point of the metal, which is easily obtained graphically by the use of testing machines. This point is the limit of strain at which the elongation of the bar suddenly becomes observable, even to unaided vision, but is best seen in the diagram taken from the machine. The writer thinks that if the tenacity and elongation are specified, it is not necessary to prescribe the yield point. The resilience or the product of these quantities is characteristic of the quality of the metal as to its properties of ductility and malleability. Engineers who deem it sufficient to determine only the yield point advise that this be made as high as possible, because for use in a structure it would be advisable to use the metal up to the highest safe strain, say one-half the yield point. This is wrong

in so far as it might lead to the raising of the yield point without corresponding increase of tenacity, which would make a brittle material liable to sudden rupture. It is probably on this account that French specifications require the yield point to be not less than one-half or more than two-thirds of the tenacity.

It is questionable whether the chemical composition of steel to be furnished should be specified, and there is a strong opinion among engineers that it is advisable to leave the methods of production in the hands of the steel-makers, while the engineer must watch the process and test the finished metal; there is, however, a difference of opinion on this point. Generally a maximum limit of phosphorus is prescribed, and sometimes of carbon also; the former is more important, and there is no doubt that more than 0.1% of phosphorus makes steel useless for structural purposes.

As to other materials, the physical tests of each charge or blow are sufficient for determining the acceptability of the material, and it seems unnecessary for the inspector to require other chemical analysis.

Table No. 4 shows that the specifications issued by the Swiss Government make the new requirement of a maximum of 0.06% sulphur for steel rivet bars. This is to prevent red-shortness in the rivets, but the same result could be obtained by the customary red-short tests. It is usually advisable for the consumer to encroach as little as possible upon the affairs of the steel-makers. As soon as the production and use of mild steel shall be governed by established rules, then its chemical analysis and composition may with confidence be left with the steel works.

No country is content with testing only for tenacity. All who have had to do with the practical examination and selection of material are convinced that this is not a complete test, and does not necessarily furnish reliable material under all conditions. It would seem, therefore, that other technical tests should be made, such as bending, forging and drop tests, the details of which are known. In Germany, in some cases an effort has been made to introduce a new kind of tenacity test, but without success. This consisted in testing pieces 2 to $2\frac{3}{8}$ ins. broad, with holes $\frac{3}{4}$ in. diameter (usually three), punched cold, at $2\frac{3}{8}$ ins. apart, center to center; the punched pieces were then subjected to the tenacity test, with the requirement that the tenacity must remain within the ordinary limits, and the fracture not show any

change of texture when compared with the fracture of unpunched pieces. The metal would not stand this test, and steel works were perfectly right in refusing to deliver mild steel under this specification. There is no better test or safer one under which to receive mild steel than that of testing blow by blow ; the examination of each blow and of the rolled or finished pieces made from it. The results gained in testing one of the blows cannot be considered as surely indicating the quality of any other. Each blow is likely to show a difference in texture and chemical composition, although usually the difference will almost disappear by good and regular management.

The selection by blows for a small quantity of steel would be impracticable ; but for large structures it should be made obligatory by the specifications.

The inspection of the steel in the state of the ingot should be an internal affair of the steel works, and one with which the engineers have nothing to do.

The last question to be discussed is the treatment and manipulation of mild steel in the shop and the field. It is not long since that it was believed to be necessary to use only hammers of copper in its manipulation. In the year 1888 a commission of French engineers, which attempted to study the question in connection with the use of such material for the bridge over the Danube near Cernavoda, had this opinion. Were this right there would be little prospect of the use of mild steel in the future. Any material requiring such careful handling could not be admitted in general use. There is no apparent reason why material which can be punched without cracking or sensible hardening at the holes, and which stands such severe usage under drop and bending tests, even after subjection to severe cold,* should not be used in an ordinary way.

A good mild steel can be worked as readily as wrought iron in the shop or the field, and even bear still harder treatment. It was, however, often thought necessary to require preliminary annealing to remove the initial strains due to rolling. The annealing is undoubtedly of great advantage to all steel above 64 000 lbs. strength per square inch, but it is questionable whether it is necessary in softer steels. The distortions due to heating cause trouble in subsequent

* Stahl und Eisen, 1892, No. 4 and No. 13. Centralblatt der Bauverwaltung, 1892, pages 68 and 83.

straightening, especially of thin plates; and very long pieces cannot be properly annealed on account of lack of facilities for such purpose at the mills. It cannot be denied, however, that annealing produces greater toughness.

In a general way all unannealed mild steel for a strength of 57 000 to 64 000 lbs. may be worked in the same way as wrought iron. Rough treatment or working at a blue heat must, however, be prohibited. Such treatment cannot be borne by wrought iron, although it does not suffer so much as soft steel. Shearing is to be avoided, except to prepare rough plates, which should afterwards be smoothed by machine tools or files before using (see Table 4, Nos. 7–10). Drifting is also to be avoided, because the edges of holes are thereby strained beyond the yield point. Reaming drilled holes is not necessary, particularly when sharp drills are used and neat work is done. A slight countersinking of the edges of drilled holes is all that is necessary. Working the material while heated should be avoided as far as possible, and the engineer should bear this in mind when designing structures. Upsetting, cranking and bending ought to be avoided, but when necessary the material should be annealed after completion.

The question of riveting is an important one, especially that as to whether the heading of steel rivets is better done by machine or hand work, on account of the danger of working at a blue heat. The riveting of a mild steel rivet should be finished as quickly as possible, before it cools to the dangerous heat. For this reason machine work is the best. There is a special advantage in machine work from the fact that the pressure can be retained upon the rivet until it has cooled sufficiently to prevent elongation and the consequent loosening of the rivet. It is undoubtedly true, also, that rivets beyond 1 in. diameter cannot be well driven by hand work; but such rivets are very seldom used. European bridge-builders, especially those on the Continent, prefer hand work, on account of the expensiveness of the other, and also on account of the difficulty in using a machine upon all the rivets to be driven in the field, which are among the most important in the structure.*

The writer, in closing this paper, desires to state that it is written for the purpose of giving a general view of the use of mild steel throughout the world, to show the importance of further tests, and to

*Notice of the erection of Iron Bridges in America. "Stahl und Eisen," 1891, No. 4.

show that, with the present knowledge that we have concerning the manufacture and use of mild steel, engineers and architects are abundantly justified in accepting it, under proper restrictions, for all classes of structures.

LIST OF THE MOST REMARKAB

No.	Name and site of the Bridge.	Time of erection.	Built or designed by	Dimensions. No. of spans.	Dimensions. Length. Feet.	Kind of materi
1....	* "Honig" Bridge, Königsberg, Prussia....	1880	Frühling, Union Foundry, Königsberg......	1	42	Acid Martin....
2....	"Hohe" Bridge, Königsberg, Prussia......	1882	Frühling, Union Foundry, Königsberg............	1 2	63 88	Acid Martin....
3....	Railway bridge over the Firth of Forth Queensferry, Scotland..................	1883–1890	Fowler & Baker.......... Arrol & Co	2 2	1 700 685	Acid Martin....
4....	Railway pin-fastened bridge for the Deli-Spoorweg Company, Sumatra...........	1885	Harkort, Duisburg, Germany..............	21	33–100	Thomas........
5....	*Kottel Bridge, Königsberg, Prussia........	1886	Frühling, Union Foundry, Königsberg......	1 2	61 55	Acid Martin....
6....	*Tower Bridge over the Thames, London .	1886 Still in erection.	Barry...................... Arrol & Co..................	1 2	180 270	Acid Martin....
7....	*Elbe Bridge, Melnik, Bohemia............	1887	Bridge Works, Prague..	4 1	193 158	Thomas........
8....	*Road bridge, Osaka, Japan......	1887	Harkort, Duisburg, Germany................	2	216	Acid Martin....
9....	Swing bridge over the "Magdeburg" Harbor, Hamburg......................	....	Harbor Department	1 2	173 52	Thomas........
10....	Moldau Viaduct, near Cerwena, Railway Tabor-Pisek, Bohemia.................	....	Austrian State Railway...	3	262	Basic Martin...
11....	Bridges of Gagnières and Iseron, Paris-Lyon-Med. Railway, France............	1887–1889	....	3	170	Basic Martin...
12....	*Two foot bridges at the "Jonas" and "Hafenthor," Hamburg................	1888	Klönne, Dortmund, Germany......	1 1	59 66	Thomas and ba Martin.......
13....	*Bridge of Piazza-Pia, over the Tiber, Rome.....................................	1888–1889	Savigliano Works, Italy...	1	330	Thomas........
14....	Thirty-seven railway bridges, Deli-Spoorweg Company, Sumatra................	1888–1889	Harkort, Duisburg........	37	Up to 200	Thomas........
15....	Viaduct do Châ, at Sao Paôlo, Brazil........	1889	Harkort, Duisburg......	4 1	98 52	Thomas........
16....	Bridge on the line from Lons le Saulnier to Champagnole, France...............	1889	....	1	230	Basic Martin...
17....	"Wallgraben" Bridge, near Marienburg, line Dirschau-Königsberg, Prussia......	1889–1890	Harkort, Duisburg........	10	59	Basic and ac Martin.....
18....	Railway bridge over the Rio Samala, Brazil..	1890	Harkort, Duisburg........	1	180	Thomas........

TABLE No. 1.

ost Remarkable Mild-Steel Superstructures of Bridges Built in the Decade 1

.	Specifications for the Material of the Superstructures.			
th. t.	Kind of material.	Total weight. Tons. 1 000 kg. = 2 204 lb.	Tenacity in pounds per square inch.	Yi Pound
	Acid Martin........	23.5	For bars .... 71 000 For plates............. 64 000	....
	Acid Martin........	130.0	.... 64 000 For rivets .... 68 000 55 500 Shearing strength.	....
	Acid Martin........	56 000	Compressed members..75 000 to 82 000 Tension members......67 000 to 74 000 Rivets.................50 000 to 54 000 Shearing strength.	....
00	Thomas............	156	.... 54 000 to 60 000	......
	Acid Martin........	108.1	.... 60 000 For rivets............ 64 000 51 000 Shearing strength.	....
	Acid Martin........	13 000	.... 60 000 to 71 000 For rivets........... 59 000 to 67 000	....
	Thomas............	700	Without specification.	......
	Acid Martin........	339	.... 74 000	......
	Thomas............	400	.... 59 000 to 64 000	......
	Basic Martin.......	968	.... 50 000 to 64 000 For rivets............ 50 000 to 57 000	....
	Basic Martin.......	....	.... 60 000 $\pm$ 3 000	Lengt Trans
	Thomas and basic Martin..........	80	.... 53 000 to 63 000	......
	Thomas............	862	.... 60 000 to 71 000	......
200	Thomas............	436	.... 54 000 to 60 000	......
	Thomas............	411	.... 54 000 to 60 000	......
	Basic Martin.......	....	.... 60 000 $\pm$ 3 000	Len Tra
	Basic and acid Martin.......	260	.... 57 000 to 64 000 For rivets............ 51 000 to 57 000	....
	Thomas............	106	.... 54 000 to 60 000	......

* Road bridges.

ADE 1880-90.

TS.		
Yield point. Pounds per square inch.	Elongation. Percent.	Remarks.
	20	Nos. 1, 2 and 5. Material from the Steel Works of "Phönix" at Eschweiler Aue, Germany.
	20	
	22	Nos. 2 and 5, a single lever-draw span and two truss spans.
	22	
	17	
	20	
	20	
	20-22	
	24	No. 6. Combination of a stiffened suspension bridge, together with an elevated foot bridge.
31 000	20	No. 7. The Prague Works furnished since 1887-90, also about 700 tons of small road bridges up to 91 ft. length and 84 tons railway bridges built partly in Thomas and partly in Martin.
	20	
	25	No 8. Moreover, three road bridges in Thomas for Japan and Brazil. Weight, 142 tons. Specification like No. 4.
37 000	25 Contraction 50	No. 9. 0.10 C.; 0 05 P.; 0.35 M.; 0.02 Sil.; 0.02 S., were stipulated.
		No. 10. Chemical analyses gave as follows: 0.062 - 0.085 C. 0.016 - 0.034 P. 0.152 - 0.210 Mn. 0.015 - 0.030 S.
	28-22	
	32-26	Afterwards followed about 2 600 tons smaller plate and girder bridges in the Austrian State Railway, 262 spans up to 223 ft. length in basic Martin mild steel.
Lengthwise.. 34 000 Transverse.. 31 000	Lengthwise .. 25 Transverse... 18	No. 11. Elongation measured in 4-in. lengths.
	20	No. 12. The same work furnished in 1888-90 140 tons smaller road bridges up to 82 ft. length Thomas and Martin mild steel combined.
28 000	18-25	
	20	
	20	
Lengthwise 34 000 Transverse 31 000	Lengthwise .. 25 Transverse... 18	
35 500	20	No. 17. Harkort furnished, moreover, 1890, fifteen railway bridges for the Kinschiu Railway in Japan; 13 road bridges for Transvaal, in Africa, and two road bridges near Santos, in Brazil. Total weight, about 1 400 tons. Thomas mild steel.
	25	
	20	

No.	Name and site of the bridge.	Time of erection.	Built or designed by
1....	Weichsel bridge at Fordon. Line Bromberg-Fordon-Culmsee, Prussia	1891-93	Mehrtens, Gutehoffnungshütte and Harkort, D
2....	*Swing bridge in the Harbor of Lübeck, road and single track railway	1891	City of Lübeck, Gutehoffnungshütte, Sterkrade
3....	Donau bridge near Czernavoda, Railway Czernavoda-Küstensche	1891	Saligny, Fives-Lille
4....	*Elbe bridge Loschwitz-Blasewitz, Saxony	1891-93	Köpcke and Krüger; Königin Marienhütte, Zwi
5....	Oder bridge, near Alt-Rüdnitz. Line Wriezen-Jädickendorf, Prussia	1891-92	Royal Railway Department, Berlin, Klönne, Dor
6....	Single track Elbe bridge at Niederwartha, Saxony. Line Berlin-Dresden	1891-92	Klette and Bahse, Lauchhammer
7....	*Road bridge over the Sesia at Ghislarengo, Province Novara, Italy	1891-92	Savigliano works
8....	Bridge over the Tanaro. Line Genova-Asti, Italy	1891	Savigliano works
9....	*Road bridge over the Reno, Province Ferrara, Italy	1891	Savigliano works
10....	Three bridges of the lines Schönberg-Hirschberg-Waldheim-Kochlitz A. O. State Railway, Saxony	1891-93	Poppe and Baumann
11....	*Twenty road-bridges for the Dutch Colonies. India	1891	Colonial Minist., Hague. Gutehoffnungshütte, S
12....	Viaduct at Lapio. Line Avellino-Rocchetta	1892	Impresa Industriale Italiana Castellamare
13....	Four bridges over the Taro. Line Parma-Spezia, Italy	1892	Impresa Industriale Italiana Castellamare
14....	*Crossing of Waltherstreet over the switching-station, Dresden-Friedrichstadt, Saxony	1892	Prohaska, Lauchhammer
15....	Donaubridge at Regensburg. Bavarian State Railways.	1892 still in erection.	....
16....	*Road bridge over the Caledon, Orange Free State	1892	Harkort, Duisburg
17...	*Moldau bridge at Moldauthein, Bohemia	1892	Bridge-work, Prague
18....	Twenty-six bridges of the Nederlands South African Railway Company, Amsterdam	1892-93	Gutehoffnungshütte, Sterkrade
19....	Crossing of Beussel street at Berlin, City Railway	1892	Betriebsamt (Board of Managers) Gutehoffnun Sterkrade
20....	Bridge over the Elbe, near Hamburg, line Venlo-Hamburg	1892-93	Royal Railway Department, Altona. Gutehoffnun
21....	Wertach bridge at Augsburg, Bavarian State Railways	1892-93	....
22....	Railway viaduct over the Tjitandoci, Java	1893	Colonial Minst. Holland, Harkort, Duisburg
23....	The crossing over Falken street at Dresden	1893	Gutehoffnungshütte Sterkrade and Lauchhamme
24....	Under bridge of the Trankgasse and Johannis street at Cologne	1893	Betriebsamt Köln-Düren. Gutehoffnungshütte, St
25....	Enz bridge at Besigheim, State Railway, Würtemberg	1893 still in erection.	....

* Road bridges.
† Vorschriften für Lieferungen von Eisen und Stahl aufgestellt vom Vereine deutscher Eisenhüttenleute. Düsseldorf
‡ Hannoversche Zeitschrift des Architekten und Ingenieur Vereins 1860, 1861, 1888 and 1889.

TABLE No. 2.

of the Most Remarkable Basic Mild-Steel Bridges and Viaducts Built in Europe Since the

igned by	Dimensions.		Specification for the Material of Superst		
	No. of spans.	Width, feet.	Kind of material.	Total weight, tons. 1 000 kg. = 2 204 lb.	Tenacity in pounds per square inch.
e and Harkort, Duisburg.	5 13	328 203	Basic Martin Thomas	11 000	55 500 to 64 000 For rivets 51 000 to 57 000
gshütte, Sterkrade	1 1	33 81	Basic Martin.	296	54 000 to 63 000
....	1 4	623 460	Basic Martin	....	60 000 to 67 000 For rivets 54 000 to 63 000
Marienhütte, Zwickau...	1 2	482 203	Basic Martin	3 238	51 000 to 64 000 Rivets wrought iron.
erlin, Klönne, Dortmund.	3 13	213 115	Thomas	1 300	53 000 to 63 000
ner	3 14	203 69	Basic Martin	1 100	51 000 to 64 000
....	7	138	Basic Martin	640	....
....	2 1	161 197	Basic Martin	328	60 000 to 71 000
....	2 1	121 157	Basic Martin	225	60 000 to 71 000
....	....	....	Basic Martin	1 714	51 000 to 64 000
hoffnungshütte, Sterkrade.	20	39 131	Basic Martin	357	Specifications of the Society
astellamare	3	318	Basic Martin	1 020	....
astellamare	1 1 3 3	285 164 118–138 111–141	Basic Martin	1 364	....
....	22	33–48	Basic Martin and Thomas	1 438	51 000 to 64 000
....	5	157	Basic Martin and Thomas	650	
....	6	148	Thomas	484	54 000 to 60 000
....	2	196	Thomas	344	........................Without
e	26	16–66	Basic Martin	343	..............German Standard
ers) Gutehoffnungshütte	1	62	Basic Martin	118	54 000 to 63 000
ona. Gutehoffnungshütte	3 4	328 75	Basic Martin	2 200	57 000 to 64 000 For rivets 51 000 to 57 000
....	3	197	Basic Martin and Thomas	380	....
ort, Duisburg	3 2 1	203 26 98	Basic Martin and Thomas	1 045	53 000 to 57 000
and Lauchhammer	1 1 1	150 82 71	Basic Martin	567	51 000 to 64 000 For rivets 48 000 to 63 000
hoffnungshütte, Sterkrade	1 1	43 66	Basic Martin	700	53 000 to 63 000
....	5 3	118 154	Basic Martin	588	

leute. Düsseldorf, 1889.

THE YEAR 1890.

PERSTRUCTURES.			
uare	Yield point, pounds per square inch.	Elongation, percent.	REMARKS.
	35 000	20	No. 1. P not above 0.10 per cent. Reception blow by blow.
00	....	25	
	....	....	No 2. The product of the tenacity and the elongation (resilience, Arbeitsziffer, capacité de travail) must reach the number 1 000 (for kilogram and square millimeter, or 1 420 000 for pounds and square inches). Chemical composition stipulated.
00	34 000	21-16	
	31 000 to 41 000	20-30 Contraction 40-65	No. 4. Highly remarkable stiffened truss suspension bridge, with three hinges, system Köpcke. Nos. 4 and 5. P not above 0.10 per cent ‡
	....	20	No. 5. The works of Klönne furnished up to 1893 also several smaller bridges. Weight about 1 000 tons.
	33 000	20	
......	Like	Nos. 8-9.	Nos. 7-9. In Italy, the Saviglian works furnished also three military bridges, 118 ft. length; weight, 260 tons, in Thomas steel, and numerous road and railway bridges. Among them may be named the viaduct over the Formia (2 spans of 152 ft.), etc. At the present time in Italy, there are finished or in erection about 13 000 tons of mild-steel bridges.
	28 000	18-25	
	28 000	18-25	
	33 000	20	
ciety	of German Steel	Work Managers.†	
......	Like Nos. 8-9.		
......	Like Nos. 8-9.		
	33 000	20	No. 14. Only the floor bars and the quadrant bars of the columns are of Thomas steel.
	....	20	
thout	specifications.		
ndard	Specifications (Table	IV).	
	....	20	
	33 000	20	No. 20. P not above 0.09 per cent. Reception blow by blow.
000	....	25-30	
......	....	....	No. 21. Moreover, since 1891, on the Bavarian State Railways four bridges (of about 600 tons weight), and roof structures for the station and the engine-house (500 tons) at Munich, besides about 1 300 tons smaller bridges have been erected.
	Resilience 900 for meter, or 1 280 square inches.	kilogram per sq. milli- 000 for pounds and	No. 22. These well-known works furnished, since 1892, 31 railway bridges of the Roumanian State railways (1 470 tons), 32 railway bridges for the railway Woochang-Hanyang in China (332 tons), 29 railway bridges for the Kiuschiu line in Japan (100 tons), and several smaller bridges for Roumania, Sumatra, Brazil, etc. Total about 6 000 tons Thomas and Martin metal from 1892 up to the beginning of 1893.
	33 000	20	
000	....		No. 23. P not above 0.10 per cent.
	....	20	

TABLE No. 3.

PRODUCTION OF BASIC MILD STEEL IN VARIOUS COUNTRIES.

NAME OF THE COUNTRY.	1891.		1892.	
	Total in tons. 1 000 kg. = 2 204 lbs.	Containing under 0.17 % carbon.	Total in tons. 1 000 kg. = 2 204 lbs.	Containing under 0.17 % carbon.
1. Germany and Luxemburg.............	1 779 779	1 314 781	2 013 484	1 616 783
2. England............................	436 261	350 818	406 839	317 585
3. France	255 401	173 880	287 528	196 190
4. Austria-Hungary....................	221 212	95 907	288 122	212 408
5. Belgium, Russia and United States.....	187 882	111 172	206 667	129 028
Total.............................	2 880 535	2 046 558	3 202 640	2 471 992

No.	Name of the authority or society.	Kind of material.	Tenacity Tests. Tenacity. Pounds per square inch.	Elongation in 8 ins. Per cent.	Yield point, pounds per square inch.
		A. Specifications for Ships and Boilers.			
1....	English Admiralty............	Plates for vessels and boilers..	57 000 to 66 000	20	
2....	German Admiralty..........	Plates for boiler shells........	60 000 to 67 000	20	
		Fire-plates for boilers........	60 000 to 64 000	20	
		Plates of vessels..............	63 000	20–25	
3....	Lloyd's Register, England..	Plates for boilers.............	58 000 to 67 000	20	
		Plates of vessels..............	63 000 to 71 000	16	
4....	Bureau Veritas, France. ...	Plates of vessels..............	60 000 to 71 000	20	....
		" for boilers............	55 500 to 68 000	26–20	
			48 000 to 54 000	32–27	
5....	Board of Trade, England....	Plates for boiler shells........	60 000 to 71 000	20	
		Fire-plates for boilers........	48 000 to 67 000	20	
6....	Germanic Lloyd, Germany.	Plates of vessels..............	58 000 to 70 000	20	....
		" for boilers..............	50 000 to 68 000	26–20	
		B. Specifications for Bridges and other Buildings.			
7....	French Ministry of Public Works, August, 1891......	Plates and bars at least.......	60 000	22	30 000 to 40 000
		Rivets " "	54 000	28	
8....	Austrian Ministry of Commerce, 1892	Plates and bars...............	50 000 to 64 000	28–22	....
		Transverse....................	50 000 to 64 000	26–20	
		Rivets	50 000 to 57 000	32–26	
		Ingot steel for bearings......	81 000	10 at least.	
9....	Standard specifications of German societies, 1892...	Bars and plates (of ½ to 1½ ins thickness) lengthwise.......	53 000 to 63 000	20	....
		Transverse....................	51 000 to 64 000	17	
		Rivets and screws.............	51 000 to 60 000	22	
		Ingot steel for bearings.......	64 000 to 85 000	10	
10....	Federal Council of Switzerland			Resilience*	....
		Bars and plates, lengthwise...	57 000 to 64 000	1 280 000	
		Universal and flange plates, Transverse.................	51 000 to 64 000	1 140 000	
		Rivets and screws............	51 000 to 60 000	1 420 000	

* Resilience (Arbeitsziffer, cap

TABLE No. 4.

…AL SPECIFICATIONS FOR MILD-STEEL STRUCTURES IN SEVERAL COUNTRIES.

…ld point, …unds per …are inch.	OTHER TESTS. For bars and plates.	OTHER TESTS. For rivets and s…
....	No. 4. For plates of $\frac{1}{4}$ in. (6.5 mm.) thickness, or less 16% elongation sufficient. Recommend fire-plates not above 62 600 lbs. tenacity and not less than 22% elongation; for undulated fire-plates, the like not above 57 000 lbs. and 25 per cent.	
....	No. 6. Recommend fire-plates not above 60 000 lbs. and not less than 22.5 per cent. For plates above 1 in. (25 mm.) thickness, the admissible greatest tenacity shall be taken for each increase of $\frac{1}{16}$ in. (2 mm.), about 710 lbs., less than the numbers of the table.	
…0 to 40 000	No. 7. Bending tests with pieces which have been punched and quenched, in such manner, that the ends of the testing-pieces touch together without crack.	....
....	No. 8. Customary bending test and quenching test with test pieces of 2 — $3\frac{1}{8}$ in. (50–80 mm.) breadth and 180° angle of bending : *a.* For material of 50 000 lbs. tenacity, the sides of the test-pieces must quite touch one another after bending. *b.* Material of 64 000 lbs. tenacity, must bend round a pin, whose diameter is equal the thickness of the piece. The same test to be made round a pin whose diameter is five times the thickness of piece, with nicks made in the piece by a stroke of chisel up to $\frac{1}{10}$ thickness of piece transverse to the rolling direction. B. *a.* Angle of bending 150°. *b.* Angle of bending 90°, causing no suddenly entering thorough crack to appear. Plate pieces heated red must be bent quite together over a sharp edge.	No. 8. Ordinary bending test in … sides of piece touch quite toge… pin whose diameter is like tha… straightening up to an angle o… Upsetting test at red heat up to c… Upsetting test at red heat and fo…
....	No. 9. Quenching test, the diameter of the loop at the bend in test of pieces cut lengthwise must be no greater than the thickness of the piece, and if cut transversely, not more than twice that thickness. Red short test. The test-piece must be heated to redness, and forged to $\frac{1}{4}$ x 1.6 ins. (6 x 40 mm.), then punched by a punch $\frac{13}{16}$ in. (20 mm.) diameter. The hole to be enlarged afterward to 1.2 ins. without cracking.	No. 9. Quenching test. Diamet… to be half of the thickness of r… Upsetting test up to one-third o…
....	No. 10. Ordinary bending and quenching tests. Pieces 2 ins. (50 mm.) breadth. Diameter of pin equal two-thirds thickness of piece in longitudinal sections, three halves thickness for transverse sections, and double thickness for universal bars. Red-heat bending-test. Sides must touch quite together. Quantity of P not above 0.1 per cent.	No. 10. Bending test as for bars… Upsetting test. Length of rivet… and to upset up to one-third. Quantity of sulphur not above 0…

…eitsziffer, capacité de travail) or product of tenacity by elongation, expressed in pounds per square inch.

	REMARKS.
s and screws.	
....	No. 7. All rivet holes are to be drilled or reamed about $\frac{1}{32}$ in. (1 mm.) after drilling. All shearing faces (Schnittflächen) are to be trimmed at least $\frac{1}{32}$ in. (1 mm.).
test in such a manner that the te together. Bending round a like that of the rivet, and re- angle of 90°. up to one-third rivet length. and forging at blue heat.	No. 8. Only basic Martin mild steel admitted. Shearing faces to be trimmed about $\frac{1}{16}$ in. (2 mm.). All rivet-holes to be drilled.
Diameter of the loop (Schleife) ess of rivet. third of the rivet length.	No. 9. Reception blow by blow, if stipulated. From each blow there are to be tested three pieces at most and from each 20 pieces a single piece. Otherwise there are to be tested from each 100 pieces five, and at most from each 2 tons of the same bars a single piece.
or bars. of rivet to be twice the diameter third. above 0.06 per cent.	No. 10. Obligatory reception blow by blow. From each blow are to be ascertained the quantities of M. and P., for rivet bars also of S. From each 10 blows also C, Si and S.

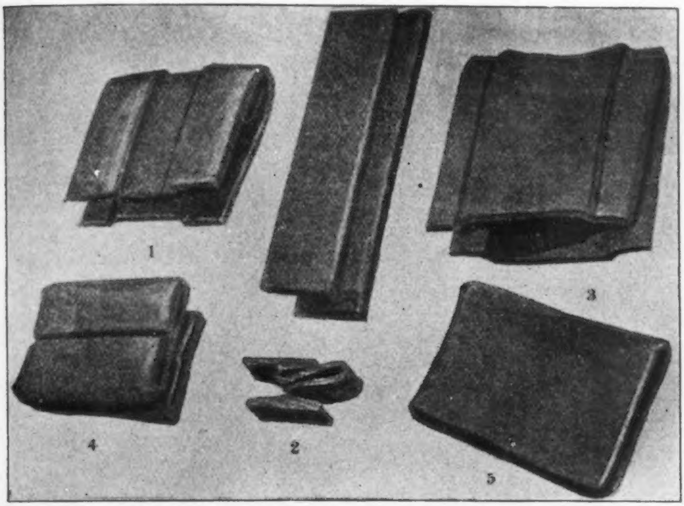
nch.

TABLE No. 5.

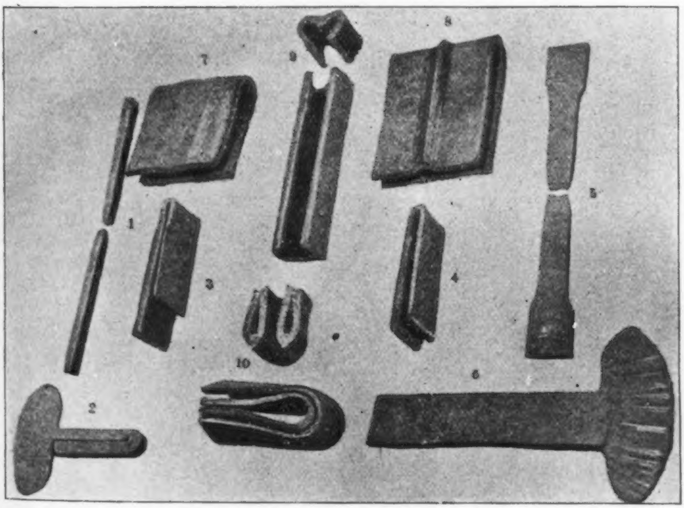
RESULTS OF TRANSVERSE TESTS, WITH PLATES AND BARS, GIVING NUMBER OF TEST PIECES REJECTED FOR FAILURE OF TRANSVERSE TESTS.

Quality of material tested.	From universal plates. 234 test pieces in length. 234 test pieces transverse.	From plates. 193 test pieces in length. 193 test pieces transverse.	From bars. 40 test pieces in length. 40 test pieces transverse.
Pounds per square inch.			
Tenacity 53 000 to 63 000, and 20% elongation	63 pieces = 27.00%	22 pieces = 11.42%	1 piece = 2.5%
Tenacity 53 000 to 63 000, and 17% "	43 pieces = 18.37%	17 pieces = 8.81%	1 piece = 2.5%
Tenacity 51 000 to 64 000, and 17% "	24 pieces = 10.00%	7 pieces = 3.78%	1 piece = 2.5%
Tenacity 51 000 to 64 000, and 15% "	19 pieces = 8.12%	3 pieces = 1.60%	0 piece = 0.00%

PLATE 1.—BASIC MARTIN O.-H. STEEL FROM THE FORDON BRIDGE.

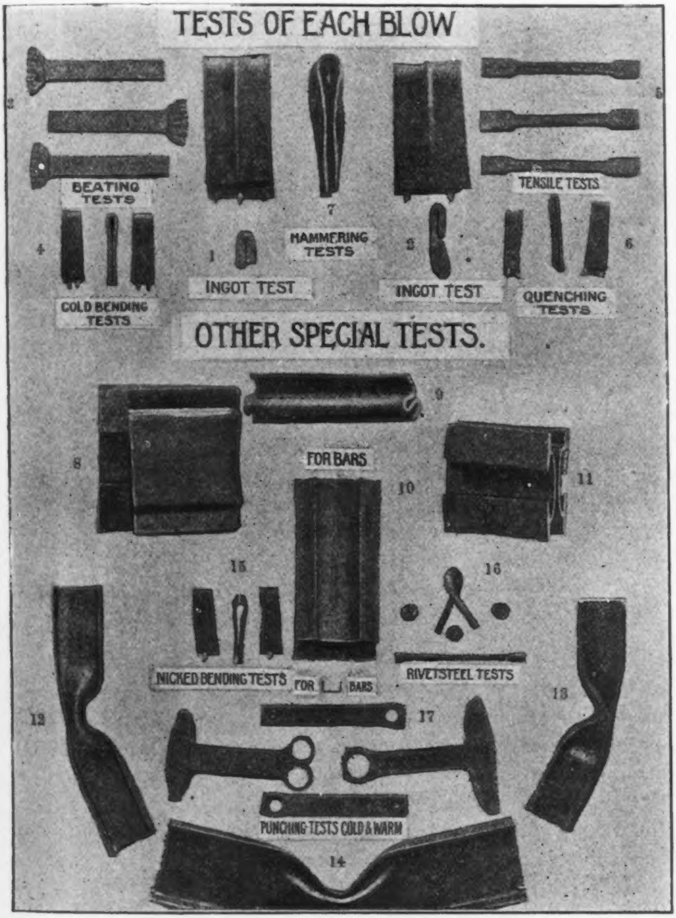


1-5. Special Drop and Bending Tests.



1-2. Ingot Tests. 3-4. Bending Tests. 5. Tensile Test. 6. Beating Test. 7-10. Special Drop and Bending Tests.

PLATE II.—THOMAS MILD STEEL FROM THE FORDON BRIDGE.



AMERICAN SOCIETY OF CIVIL ENGINEERS.

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THE USE OF BASIC MILD STEEL AS MATERIAL FOR CONSTRUCTION IN GERMANY.

By C. WEYRICH, Engineer of River and Harbor Board at Hamburg, Germany.

Prepared for the International Engineering Congress of the Columbian Exposition, 1893.

Among the iron-ore-producing countries of the world, Germany holds the third position. The United States and Great Britain, being respectively first and second, are followed closely by Germany, while Spain follows at a much greater distance.

The total produce of iron ore for all countries in the year 1890 amounted to about 67 000 000 tons, distributed as follows :

	Tons.
United States	17 500 000
Great Britain	14 000 000
Germany	11 500 000
Spain	5 000 000
All the other countries	19 000 000
Thus making a total of	67 000 000

NOTE.—Discussions on all papers presented to the International Engineering Congress will be published simultaneously in the number for December, 1893.

About 40%, or 27 000 000 tons, of pig iron was made from this quantity of iron ore, and was converted into:

	Tons.
Wrought iron	7 500 000
Steel	12 000 000
Castings	7 500 000
Making a total of	27 000 000

Of these 12 000 000 tons of steel, 2 500 000 tons were basic or Thomas steel, of which 2 000 000 tons contained less than 0.17% carbon.

The total quantity of 2 500 000 tons of basic steel was manufactured by the different countries as follows:

	Tons.
Germany	1 500 000
Great Britain	500 000
France	250 000
Austria	125 000
Belgium, Russia and United States	125 000
Together	2 500 000

The commercial value of the iron ores produced in Germany in the year 1890 was estimated to be about 48 000 000 marks, or about 4.2 marks per ton. The export of Germany in the year 1890 amounted to nearly 2 000 000 tons, from which amount France and Belgium received about equal parts. The import reached nearly 500 000 tons, chiefly of Spanish origin.

The total output of pig iron in Germany was 4 658 000 tons, and of these there were used in the manufacture of—

	Tons.
Steel	2 256 000
Wrought iron	1 581 000
Cast iron of 2d fusion	781 000
The rest being 1st fusion, old iron and graint of pig iron from the blast furnace cinder	40 000
	4 658 000

The manufactured products were:

	Tons.
Steel	1 614 000
Wrought iron	1 486 000

Or in detail :

	Steel. Tons.	Wrought Iron. Tons.
Rails	560 000	11 000
Ties	130 000	16 000
Tires, railway axles, wheels	93 000	16 000
Merchant iron, plates, etc	515 000	1 258 000
Wire	217 000	122 000
Various materials	99 000	63 000
	1 614 000	1 486 000

Since this time the change in the production in Germany has not been very marked, the quantities being for—

	Pig Iron. Tons.
1890	4 658 000
1891	4 452 000
1892	4 793 000

Other countries appear to have fluctuated in like manner; for instance, the United States, the most productive country, shows also a decrease for the year 1891, which was balanced in 1892.

The output was for the three consecutive years :

	Pig Iron. Tons.
1890	9 349 000
1891	8 412 000
1892	9 303 000

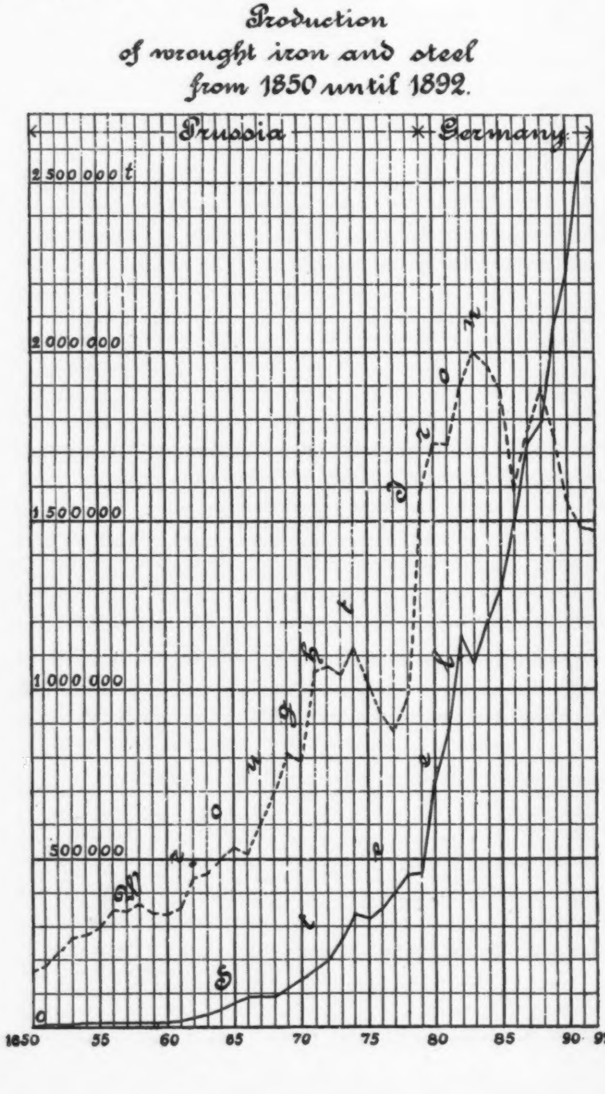
It may therefore be said the output for 1890 may be taken as a fair average for the present production. Only in the production of Thomas steel has a considerable progress been made at the expense of wrought iron.

The returns for 1892 in proportion to 1890 are as follows :

	1890. Tons	1892. Tons.
Germany	1 500 000	2 000 000
Great Britain	500 000	500 000
France	250 000	250 000
Austria	125 000	250 000
Belgium, United States, Russia.	125 000	250 000
Thus making a total of	2 500 000	3 250 000

It will be seen that the greatest increase was in Germany.

The development in the production of wrought iron and steel in Germany since 1850 is shown in the diagram.



Bessemer's invention of 1861 and the introduction of the acid Martin process in 1865 gave only a moderate impulse to the somewhat unimportant German steel industry. The German ores could not be worked in the acid process, as they contained too much phosphorus, and had, therefore, to be mixed with imported ores, principally of Spanish origin, in order to produce an available metal. In this way the existing demand for steel rails, for instance, was covered. But the price of the acid steel being too high, it could not compete successfully for purposes where wrought iron was usually applied. It was through the celebrated invention of Thomas and Gilchrist, in 1878–79, which enabled the phosphorus to be extracted by means of fitting a basic lining to the converter, that a great change in the production took place.

Since that time the German ores have been easily converted into steel, the consequence being a great increase in the production of steel. In the year 1880, the year following the introduction of the Thomas process, the produce of steel was double that of the previous year, viz., 750 000 tons against 470 000 tons; and in the year 1892 the output reached 2 650 000 tons, or six times as much as that of the year 1879.

During the same period a great fluctuation took place in the manufacture of wrought iron. Until the year 1883 the production of wrought iron was still increasing, and reached its highest level with 2 002 000 tons. After that time the production, after a short period of revival, gradually diminished to 1 470 000 tons in the year 1892.

A visit to the German steel and iron works confirms this development. While the steel works are increasing in number and extent, the puddling hearths disappear more and more, so that it appears to be a matter of time only when the production of wrought iron will be of secondary moment.

In 1886 the basic process was supplemented by the introduction of the basic Siemens-Martin process. By this new method new friends were gained for the use of steel. The stormy flow of the Thomas process was found objectionable by many, and there were no means of influencing its course. The Siemens-Martin process requires more time to carry it through; it allows a regulation in the formation of the flow. At present both processes are used promiscuously. The majority of the consumers does not attach importance to the method

in which the material is manufactured, while some prefer Siemens-Martin steel.

The production of Bessemer material has scarcely kept on the same level as in earlier times. At present about 12% of the whole quantity of steel is made by the acid process. About 13% of the remainder is Siemens-Martin steel, and 87% Thomas steel.

The respective figures for 1892 are :

	Tons.
Bessemer steel	310 000
Basic Siemens-Martin steel	300 000
Thomas steel	2 040 000
Thus making a total of	2 650 000

During the first years following the introduction of the Thomas process, it was the hard kind of material only that was produced, and it was principally used for rails. The production of rails in the year 1882 was 400 000 tons, of which, of course, the greater part was made by the Bessemer process. But the advantage of the Thomas steel is its softness, it is more easily manufactured, does not suffer by riveting, or accidents, does not injure in working, and is not in any way endangered by exposure to frost, at least such as is likely to be experienced in Germany, the only change in its physical properties being perhaps a very small loss of tenacity. With the progress in the manufacture of Thomas steel, its special properties enabled it to gain new ground; and this was promoted by successful improvements in the new process and the plant employed, which were the means through which a good mild material could be produced with perfect certainty. In the earlier stage Thomas steel was used principally for engineering and ship-building purposes. The German navy particularly became a great consumer. In this application the material is required to have an ultimate tensile strength of between 45 to 50 kg., or 64 000 to 71 100 lbs. per square inch; whereas, for rails, a tensile strength of 50 to 60 kg., or 71 100 to 85 300 lbs. per square inch, is demanded.

With further progress in manufacturing milder kinds of steel, this material drove away wrought iron from the field of iron constructions and soon took possession of the iron market for all general purposes, entirely excluding the competition of Bessemer steel, as this material could not be manufactured of such mildness as is required for these purposes.

The following table shows the production of the two kinds of rolled iron.

	Wrought Iron. Tons.	Mild Steel. Tons.
1882	about 1 000 000	59 000
1883	1 020 000	about 75 000
1884	1 044 000	97 000
1885	1 071 000	about 120 000
1886	1 076 000	139 000
1887	1 264 000	234 000
1888	1 276 000	349 000
1889	1 357 000	496 000
1890	1 258 000	515 000
1891	1 179 000	603 000

It will be seen that during the 10 years from 1882 to 1891 the production of rolled iron manufactured from mild steel increased tenfold, viz., from 59 000 to 603 000 tons, while the manufacture of the same article from wrought iron—at present the only use for this material—advanced very slowly, until in the year 1889 a point was reached from which there was a constant decrease. But as material suitable for the construction of bridges, the use of mild steel would not advance, although its use for that purpose was urgently desired, not only on account of the great demand, but also as the admission of this material, as such, would at once destroy all scruples against its use.

The slow advance corresponds with the characteristic conservatism of Germany. While in America, the country of the most unhindered inducement, novelties are always welcomed, a failure is soon excused and furnishes experience only, in Germany such mistakes are not at all admissible. He that would encounter such a failure, would suffer damage to his reputation. This accounts in a great measure for the extreme backwardness in the adoption of new material. Another drawback is that all public constructions require the approval of the government authorities, who are bound by existing instructions and do not possess the power to introduce novelties. There were still more difficulties to be encountered. The opinions as to the material to be used in the construction of bridges differed. As bridges were not frequently built, experience could not readily be gained.

Further there exists very little intercourse between the civil engi-

neers responsible for the construction and the steel manufacturers. The civil engineer in charge has no time to study the practice of steel manufacturing; he, therefore, lacks the necessary knowledge, being satisfied when he receives the material, which is offered to him as tested according to the specifications; he, therefore, does not know whether all of his wishes are at all times practicable.

The steel-maker lacks a general view of what is required and in what direction the tendency for changes in the requirements are moving, and therefore is not able to change his management accordingly. These circumstances in Germany, contrary to other countries, opposed the progress of mild steel for the construction of bridges, so that it gained ground very slowly. For these reasons it was only very recently that an agreement was arrived at, that the soft material only was to be used. This material is the only one the steel-makers can produce with the greatest possible safety and give to the civil engineer the desired guarantee.

The first very modest trials to build bridges of mild steel were made in Königsberg, in the years 1882 to 1884, by the building of two road bridges of moderate size. Then followed the erection of a bridge of larger dimensions in Hamburg, which was executed by the author of this paper for the State of Hamburg. The bridge served for the use of pedestrians and carriages, and also for two sets of railway lines, and was the first railway bridge in Germany made of mild steel. After the successful completion of this work, more bridges were built of mild steel in Hamburg.

The Prussian Railroad Board then used the same material. At first it was tried with a small railway bridge, and a bridge of larger dimensions is at present under construction, crossing the River Weichsel. Recently, other railway boards have also begun the use of this material in bridges, so that the use of mild steel for these purposes has found the right direction.

All these expectations will be advanced, nevertheless, by creating uniform specifications for mild steel constructions.

The three great associations of German engineers, viz.:

(1) "Der Verband deutscher Architecten und Ingenieur Vereine,"

(2) "Der Verein deutscher Ingenieure,"

(3) "Der Verein deutscher Eisenhüttenleute,"

constituted in the year 1891, a committee for examining this question,

and this committee formulated a standard specification, which was agreed to by the above-mentioned associations, and as the assent has been promised by the German official authorities, this will become the standard for Germany.

Before they entered into the deliberation, the question was raised whether these specifications should extend to the material used for ship-building. But everybody was convinced that this was not advisable. The material used in Germany and abroad for ship-building purposes is of harder quality than the mild steel used for buildings, and it would be a serious matter to bring forward an alteration for Germany only, on account of the classification of ships.

The principal conditions agreed upon were as follows:

The mild steel must show a smooth surface without flaws and blisters and shall not have cracks on the edges and must be sound in all parts.

If an examination by charges is agreed to, every sample put before the official has to bear the same mark as the charge.

Of each charge submitted for approval only three samples are allowed to be taken; the highest number allowed out of each 20 pieces, or 20 pieces on which work has been commenced, is one sample; these are to selected and to be used for testing under the following conditions:

If an examination by charges was not agreed to, the selection for testing of five samples out of each 100 may be allowed; the highest number allowed is one sample out of each 2 000, or commenced 2 000, kg. of the material laid down for approval. In both cases they should use, if possible, the waste ends of the material. If all the tests correspond with the specified conditions, the respective material must be recognized as accepted. For each unsatisfactory sample of the respective material two others may be taken. If any sample of these should fail to satisfy the conditions laid down, the whole quantity of material must be rejected.

The following specifications are established for material, which is from 7 to 28 mm., or $\frac{1}{4}$ to $1\frac{1}{8}$ ins., thick; for other thicknesses special agreements are to be made.

A. Machine Tests.—The material is to have an ultimate tensile strength in the longitudinal direction of not less than 37 kg. per square millimeter, or 52 600 lbs. per square inch, and not more than 44 kg. per square millimeter, or 62 600 lbs. per square inch, with an elongation of not less than 20 per cent.

In the transverse direction the tensile strength to be from 36 to 45 kg. per square millimeter, or 51 200 to 64 000 lbs. per square inch, the elongation being at least 17 per cent.

For rivets and bolts a tensile strength of not less than 36 kg., and not more than 42 kg., per square millimeter, or between 51 200 and 59 700 lbs. per square inch, the elongation being 22 per cent.

B. Various Tests.—1. Flat-iron, special iron and plates.

a. Bending tests.

Samples are to be taken both from the longitudinal and transverse direction and to be heated properly to a low cherry-red and to be quenched in water of about 28° Celsius, and then to be bent to a loop, with an inner diameter equal to the thickness of the sample for longitudinal tests and double the thickness of the sample for cross tests. The longitudinal tests shall not show any cracks; whereas, the cross tests may show such on the surface of no great importance.

b. Test for red-shortness.

A sample of 6 mm., or ¼ in., thickness, and about 40 mm., or 1½ ins. breadth is to be forged while red hot and to be punched in this condition with a tapered punch 80 mm., or 3 ins., long and 30 mm., or 1¼ ins., in diameter at the large, and 20 mm., or ¾ in., in diameter at the small, end. The 20-mm., or ¾-in., hole is to widen to 30 mm., or 1¼ ins., in diameter, without causing any cracks.

2. Rivets and bolts.

a. Bending tests.

Round bars, after having been properly heated to a low cherry-red and quenched in water of about 28° Celsius, must be capable of being bent to a loop of which the diameter is not greater than half the diameter of the sample, and must then not show any cracks.

b. Riveting tests.

A sample of a screw bolt or rivet with a length of double its diameter is to be heated uniformly to the corresponding heat at which it will be used; it then is to be upset to one-third of its original length, without showing any cracks.

The samples of bars to be used for tensile tests are to be cut, when cold, from the piece submitted for approval and to be worked in a like manner.

The damages which may result from shearing or from punching the material are to be removed. Annealing is to be avoided, if the piece itself is not to be annealed during working. The skin of the samples taken for testing is not to be destroyed.

As a rule the samples ought to have a length of 200 mm., or 8 ins., and 300 to 500 sq. mm. or ½ to ¾ sq. ins., of transverse section.

Round bars of less than 20 mm., or ¾ in., diameter should have a length equal to 10 times the diameter.

At each end of the proper testing length the samples are to be kept longer about 10 mm. or ⅜ in., with the same section.

When the test has been made, and the fracture taken place above or below the middle third part, and if it then does not show the expected elongation, the test must be repeated.

The machine for testing must be open for easy inspection for exactness.

The samples to be selected for bending tests are to have 30 to 50 mm. or $1\frac{1}{4}$ ins. to 2 ins. breadth, or a round bar of such a thickness as will be used afterwards.

All samples are to be prepared when cold, and the edges are to be smoothed off.

Every working of the mild steel is to be done cold, or at least in red-hot condition. All work under conditions between these two temperatures is to be avoided as much as possible. If this cannot be avoided, then the finished material is to be annealed in a proper way.

If mild steel is sheared, then the material next to the section is to be taken off by planing or shaping to a depth of 2 mm. or $\frac{1}{16}$ in., excepting in more unimportant parts, such as lining pieces, etc.

All bolt and rivet holes are to be drilled, with the exception of those in lining pieces, which may be punched. The burr in the holes is to be carefully removed before fitting and riveting the pieces.

Riveting at the place of erection is to be avoided when possible.

Rules regarding the manner in which the manufacture of mild steel is to be performed have not been proposed.

Mild steel of either basic or acid origin may always be passed for application. The Bessemer steel of course will not be recognized as a suitable material, as it cannot be produced under the above-mentioned conditions.

The requirements of the specifications are that the mild steel shall shall be worked in the same state as when it left the rolling mill. A material of the proposed mildness does not require annealing.

Through annealing the material is liable to warp, and therefore has to be straightened again, the consequence being, if this is not done with good tools, that new strains will arise instead of all strains being removed.

The acceptance of mild steel by charges was left to be a matter of judgment, and accordingly the application of marks on the rolled steel will not be insisted upon. A great deal of the ordinary steel which consumers require to cover their current need, will be taken from the ironmonger and not bought from the steel works; for this reason the acceptance by charges will not be practicable. This material cannot be measured with the scale of conditions of the standard rules, as this would only tend to make the material unnecessarily costly. Material manufactured with the standard rules, being used for all more important purposes, would be warranted only by putting on the

number of the charge, and at the same time adding on it the name of the manufacturing steel works in order to base any claims on its identity. To these two marks a third one should be added, as a sign that the material will conform to the standard rules laid down. Putting all three stamps on the material, many finishing rollers being used both for wrought iron and steel, would be impracticable for different reasons. Relief stamps may hinder proper fitting when connections are made with straps, and stamps sunk in will cause a reduction in the area of the transverse section. It will be better, therefore, to do without any marking if possible. The standard rules are laid down in order to insure a reliable material for buildings requiring an absolute certainty. In such cases the material will not be bought from the ironmonger, but is to be manufactured under special inspection according to the standard rules, and is then to be tested by charges, as previously mentioned. The expense of this method of testing seems to be justified for such purposes, and is comparatively of little moment, as in most cases large quantities are dealt with.

The testing conditions relate only to thicknesses of from 7 to 28 mm. or $\frac{1}{4}$ in. to $1\frac{1}{8}$ in., as for all purposes outside of this limit the conditions would scarcely be possible. Material below 7 mm. or $\frac{1}{4}$ in. will be cooled down too much during rolling, and will consequently be too hard, the strength increases, while the elongation diminishes. A material above 28 mm. or $1\frac{1}{8}$ in. thick has not all been properly worked, and will therefore not answer the conditions laid down.

The most important factor is the strength in combination with the elongation of the material. It has been stated already that only the milder kind of steel can be used. Only a material that is free from hard places can give a guarantee as to its security. The hardening destroys the tenacity and therefore makes the material unreliable in use, and working at different degrees of temperature will create internal strains. Steel of an ultimate tensile strength of 50 kg. or 71 100 lbs., supposing normal chemical composition, approaches the limit of hardening. The highest limit for the ultimate tensile strength was made 62 600 lbs., so as to keep clear of all inclination to hardening. But the lowest strength has also its limit, because the material will become too soft and difficult to be worked. The lower limit of 23 tons seems practicable, and this leaves a play of 10 000 lbs. in the production of mild steel for building purposes. Perhaps this limit may be deemed too

wide by many, as materials of 52 600 and 62 600 lbs. ultimate strength are relatively of different nature. But it must be said that with equal chemical composition, and independent of the manufacturing works, the material appears to still have great fluctuations in the limit of strength.

The heat of the charges at the beginning and the end, the position in the hearth or ingot, the subsequent working and treatment, the ratio of the surface of the finished material to the transverse section, the pressure during rolling in the different parts of the material, as in the flanges or the web of special steels, the length of the manufactured pieces, as well as the place from which the sample is taken, either from the middle or ends, all may influence the strength of the material; for instance, there exists a certain difference of strength between plates and special steel in consequence of their being rolled in different ways, although the chemical constitution is the same in both cases. Taking all these circumstances into consideration it may be deemed necessary to allow the stipulated limit.

For bars to be used in tension and compression, no different material is prescribed, although it is not to be mistaken that safety in compression makes it desirable to introduce a harder material. The elongation was fixed at the limit of 20% in order to insure a material of sufficient tenacity. A material of this quality can be made as easily by the Siemens-Martin process as by the Thomas process with the ordinary rolling plant.

Special specifications were stated for tests in the transverse direction of the material. The supposition that mild steel is to such an extent homogeneous that there are no differences as to its properties in the longitudinal or transverse direction cannot be definitely accepted. The unavoidable air holes which are present in ingots before rolling takes place, will be lengthened longitudinally as long as rolling is done in the same direction; whereas, they will be crushed by being rolled transversely and longitudinally. In the first case the cross tests taken from this material would not give such satisfaction as the longitudinal tests of the same material, the elongation being at the same time diminished. For this reason, and in order to avoid complication, there will not be required the same elongation in cross-tests, either for plates or for special steel shapes.

The results of tensile strength developed in cross tests vary so much

that it has been considered necessary to give a wider margin in every direction, of about 1 400 lbs., from 51 200 to 64 000 lbs. per square inch.

For rivet and bolt steel a material of greater mildness than the construction material is recommended. The enormous changes of form developed during working, especially in rivets, make it necessary to have a material of the highest ductility and tenacity. For this reason the elongation and the corresponding strength have been fixed as laid down in the specification.

Besides these conditions regarding strength and elongation, normal rules are laid down relative to mechanical tests as to working, in order to ascertain in another way whether the material is too hard, or too mild.

The total testing length of the samples is fixed throughout at 200 mm., or 8 ins. Only with round steel of less than 20 mm. or ¾ in., diameter, should the length be reduced to 10 times the diameter. If the length of 200 mm. or 8 ins., should be insisted on, the prescribed elongation could not be maintained throughout, because, with a decrease in the sectional area, the elongation at the breaking point also diminishes.

As a rule the sectional area should be between 300 sq. mm. (equal ½ sq. in.), and 500 sq. mm. (equal ¾ sq. in.), larger differences being excluded. The elongation would be influenced too much. In these limits there already exist large differences. A bar of 300 sq. mm. or ½ sq. in., sectional area, which has 20% elongation, would otherwise under equal conditions have 23% elongation, having a sectional area of 500 sq. mm. or ¾ sq. in. Therefore it is not advisable to have too great a margin.

If the fracture takes place outside the middle third of the tested length, the samples are to be rejected in case the elongation is insufficient, because under these conditions the elongation cannot be taken into full account.

If possible the skin of the material should not be broken, as it has been found by experience that this diminishes the ratio of elongation.

There are no conditions laid down relative to the sectional form of samples, although the amount of elongation is influenced by the form of section. Yet such form must be taken into consideration, and the conditions laid down for elongation are so arranged as to enable the same results to be obtained with less favorable sectional forms.

With regard to the chemical composition of mild steel, no rules have been laid down. It will be accepted that, if the physical tests as fixed by the specifications are satisfied, then, also, will the chemical composition be proper. But this does not apply to every case. For one reason the chemical admixtures cannot be gauged by mechanical tests, and for another reason it may be possible to conceal bad qualities by a change in the mixing of different elements to that extent that they will not be discovered when tried under the prescribed tests, while in other respects they may appear afterwards. At all events, specifications concerning chemical composition would considerably complicate the conditions as being difficult to execute. It may be said, that the ores of Westphalia and the Rhine district, worked to basic mild steel, furnish a finished material which has the following chemical compositition:

Carbon	0.09%
Manganese	0.35%
Phosphorus	0.05%
Silicon.	0.01%
Sulphur	0.04%

The sulphur is rather high, as the German ores contain a good deal of it, and as the basic process cannot remove it sufficiently. But recently, however, with the introduction of mixing apparatus in which all the runnings of the blast furnaces will be gathered, a process has been introduced through which a considerable amount of sulphur is being expelled, so that at the present time the basic mild steel can be produced of greater purity.

With regard to the allowed strain in mild steel no specifications could be agreed upon, as this would exceed the purpose and should be left entirely to the constructor.

With all bridge constructions hitherto made in Germany, the conditions for wrought iron have been employed throughout, which allow in general a strain to be taken as high as 7 kg. per square millimeter, equal to 10 000 lbs. per square inch. An exception was made when building the previously mentioned bridge at Hamburg where the strain was raised to 9 kg. per square millimeter, or 12 800 lbs. per square inch. The weight saved by this means amounted to about 25 per cent. It is to be hoped that the regulations regarding strain will soon be

made general, and that a higher strain will be admitted for mild steel than that allowed at present for wrought iron.

Though mild steel does not possess any considerably higher ultimate tensile strength compared with wrought iron, yet the ratio of elasticity is much higher; it being in wrought iron about 16 kg., equal to 22 800 lbs., and in mild steel about 24 kg., equal to 34 100 lbs., an excess of 50 per cent.

As many civil engineers design with a fraction of ratio of elasticity, for instance with the half of it, the strain in wrought iron would be 7 kg., equal to 10 000 lbs., and in mild steel 10.5 kg., equal to 15 000 lbs. If it is not advisable to go so far, it will be at all events allowable to introduce a partial increase of the strain for the material, which may be fixed perhaps at 9 kg., or 12 800 lbs. Through this the question of cost would be favorably influenced.

Mild steel can be produced at a lower rate than wrought iron, the average price being at present 5% lower. Another advantage is that a greater strain may be allowed, which makes it in the end a decidedly more economical material. These combined advantages, together with higher qualities, will evidently secure the future of mild steel, and every extended application of such metal in general will advance its use. Not only are foundations by piles, grillages, sheet pilings of iron now made of it, but the framework for warehouses, etc., is beginning to be made of the same material, and the extension of iron building is going on in all departments.

It is to be hoped that no reaction will take place, and that those tendencies will not grow that incline toward the introduction of a harder kind of steel in order to obtain a higher limit of strain, and as a consequence a more economical construction.

Hopes are entertained that mild steel will be produced from iron and carbon only without containing other chemical substances, and that in this manner the quantity of carbon could be increased so far as to give to the material such strength that a higher strain can be employed. But the fact is overlooked that there still remains the possibility of hardening, with its dangerous consequences. Especially for bridge-building purposes this material would prove very unsuitable.

The custom in Germany, in constructing bridges of many pieces and connecting them with rivets, closely pitched, does not appear to be practicable for the use of a harder material. Another method of construction might be substituted, perhaps the application of eye-bars, as is often seen in America. Even then, the introduction of a harder steel would be of doubtful utility. It is therefore urgently desirable that the previously approved mild steel may still continue to be used for all constructions, without any alteration whatever.